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## SOIL REACTION IN RELATION TO CALCIUM ADSORPTION<sup>1</sup>

By C. O. SWANSON<sup>2</sup>

*Professor of Agricultural Chemistry, Kansas State Agricultural College*

### DISCUSSION OF TERMS AND STATEMENT OF THE PROBLEM

#### SOIL REACTION AND LIME REQUIREMENT

Various terms are found in soil literature relative to soil reaction. "Soil acidity" often refers to the reaction of moist soil toward some indicator such as litmus or phenolphthalein. "Lime requirement" refers to the amount of a calcium compound necessary to change the reaction to some chosen standard, usually the color change of phenolphthalein. The minimum amount of lime required to change the reaction to this standard is referred to as the "immediate lime requirement," while "continuous lime requirement" is an expression of the amount of lime needed to keep the soil at the desirable reaction for a period of time.

#### ACID, NEUTRAL, AND ALKALINE SOLUTIONS

The large amount of work done in recent years on hydrogen-ion concentration has served to clarify the meaning of the terms acid, neutral, and alkaline. All aqueous solutions contain, no matter what else is present, hydrogen ions and hydroxyl ions. In a neutral solution the respective concentrations of these two ions are equal. In an acid solution the hydrogen-ion concentration is in excess of the hydroxyl-ion concentration, while in an alkaline solution the reverse is true. These ideas of acidity, neutrality, and alkalinity are applicable to water suspensions and water extracts of soil.

#### THE EXPRESSION FOR SOIL REACTION

In this paper the degree of soil reaction refers to the numerical value of the hydrogen-ion concentration as determined by the hydrogen electrode. This value can also, with certain restrictions, be determined by the use of indicators. Gillespie (14)<sup>3</sup> found that there was a fairly

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<sup>2</sup> The writer desires to express his appreciation to Professors T. L. Lyon, J. A. Bizzell, and H. O. Buckner for helpful suggestions in doing this work and in preparing the thesis.

<sup>3</sup> Reference is made by number (italic) to "Literature cited," p. 120-123.

close agreement in the values obtained by the use of the electrometric and the colorimetric methods. The method of expressing this value by the symbol  $P_H$  and some number is well known. Extensive bibliographies relative to hydrogen-ion concentration are given by Schmidt and Hoagland (40) and by Clark (7).

#### ADSORPTION AND ABSORPTION

By adsorption is meant a combination of chemical substances such that the resulting product is neither a definite chemical compound nor a homogeneous mixture. When  $CO_2$  combines with  $CaO$  the product at equilibrium is a definite chemical compound. When  $HCl$  is added to water the product is a homogeneous substance. When this acid mixes with water there are no such surface phenomena as are found when a solid phase is present and absorption is used as the descriptive term. With adsorption are associated the ideas of surface and heterogeneity. When varying quantities of  $Ca(OH)_2$  are added to soil in the presence of water a series of definite chemical compounds may be formed even though their presence would be difficult to prove or disprove. That the amount of  $Ca(OH)_2$  taken up by a given quantity of soil is governed by various factors, one of which is the amount of clay, indicating a large extent of surface, was shown in a former publication (44). That the combination of soil and  $Ca(OH)_2$  when mixed in various amounts is neither a homogeneous mixture nor probably a definite chemical compound will be evident from the data to be presented. No attempt has been made to determine chemical equilibrium in this investigation; it is very probable, however, that definite chemical compounds form at equilibrium. Since there are surface phenomena and heterogeneity, the term adsorption rather than absorption is used, although some writers, notably Lyon and Buckman (31, p. 263) prefer the latter term.

#### HYDROGEN ELECTRODE IN USE WITH SOIL

A large amount of work has been done and many papers published on the subject of soil acidity. McIntire (33), Fisher (13), Ames and Schollenberger (2), as well as others, have discussed this subject fully and given extensive citations to literature. A study of the data presented by different investigators will show that the results obtained are dependent upon the methods used in making the determinations. The results from one method are therefore comparable with those of another only in a general way. The hydrogen electrode, as a means of measuring the hydrogen-ion concentration in soil, has not yet been used as extensively as some of the other devices. It has been employed to a limited extent in soil investigations by Gillespie (14), Plummer (37), Knight (26), Sharp and Hoagland (41, 23), Swanson et al. (44), and others.

To indicate qualitatively the hydrogen-ion concentration in a soil suspension or a soil extract, the hydrogen electrode offers a comparatively simple and rapid procedure, and the results are probably more accurate than those obtained by any other method. Electrometric titration as a means of determining the amount of acid or alkali required to titrate to the neutral point, or to change the  $P_H$  present to that of any other desired  $P_H$  can be used rapidly and successfully with many substances

for which indicators are unsuited. With soils electrometric titration has not come into extensive use because of certain inherent difficulties that have been pointed out by those who have used the method (26, 41). Some of these will be discussed later.

#### RELATION OF INTENSITY AND QUANTITY OF ACIDITY

The  $P_H$  value obtained by the hydrogen electrode on a soil suspension gives a measure of the actual amount of hydrogen ions present under the conditions of the experiment. This is often designated as "intensity of acidity" (14) and is very different from the total quantity of hydrogen ions which may be produced by the gradual introduction of hydroxyl ions. This point may be illustrated with the following example: A certain solution gives a reaction equivalent to  $P_H$  5. This means that there is present 0.00001 gm. hydrogen ions per liter of solution. Suppose that in this case it takes five cc. of a 0.04N hydroxid to bring 1,000 cc. of this solution to  $P_H$  7. Five cc. of 0.04N hydroxid solution contain enough hydroxyl ions to react with 0.0002 gm. hydrogen ions. In other words, if a liter is titrated, the figure which represents the total acidity is 20 times greater than the figure which represents the intensity of acidity. If it takes 5 cc. of 0.04N hydroxid to change 100 cc. from  $P_H$  5 to  $P_H$  7, the total acidity is 200 times greater than the figure which represents the intensity.

#### DIFFICULTY IN THE USE OF THE HYDROGEN ELECTRODE WITH SOIL

In speaking of the electrometric titration of soil with standard  $\text{Ca}(\text{OH})_2$ , Sharp and Hoagland remark (41): "Such a method is logically adapted to obtain the information necessary for the proper adjustment of the soil reaction by the addition of lime. There are, however, certain difficulties met with in its application to soils. One of the chief difficulties is due to the relative insolubility of the acid-forming constituents of soil which prevent a rapid attainment of equilibrium." Data given by these investigators show that the time necessary to attain equilibrium varied from 3 to 110 hours. This time factor and other difficulties are also discussed by Knight (26). That the direct electrometric titration of a soil suspension is a tedious and difficult operation is known to anyone who has tried the method. The direct titration was used in a former investigation (44), and it was noted that if observations were made soon after the introduction of the  $\text{Ca}(\text{OH})_2$  solution into a soil suspension it would usually be found that the voltage reading was greatly increased. If readings were taken at, say, five-minute or longer intervals, it would be found that the reading decreased, or the H-ion concentration gradually increased. This means that H ions are produced by more of the acid-forming constituents going into solution. This change may continue until a  $P_H$  value of, say, 6 or 5 is obtained, showing that if neutrality is desired more hydroxid must be added. As soon as this is added the voltage reading again suddenly goes up, numerically, probably beyond the equivalent of  $P_H$  7. This does not necessarily mean that too much or even enough hydroxid has been added. The readings will again gradually decrease, showing that hydroxid must again be added if neutrality is to be attained. It is necessary to repeat this process several times, until equilibrium is established at  $P_H$  7, or any other

desired figure. Furthermore, the nearer the value approaches the neutral point the longer time is required to attain equilibrium. This is particularly true with clay and silt soils.

The fact that on soils a  $P_H$  value may be obtained which indicates a larger  $H$ -ion concentration than hydroxyl-ion concentration means that the acid-producing substance is soluble and ionized, even if the degree of such solubility and ionization is small. Regardless of whether it is large or small, the gradual introduction of  $OH$  ions causes a change such that more hydrogen ions are produced. The slowness of this change is the fundamental difficulty in using the hydrogen electrode as the basis of a quantitative method for soil. Sometimes the complicated and expensive apparatus necessary is cited as an objection, but this is no more valid for soil than for the large number of other substances on which electrometric measurements are made accurately and rapidly.

#### THE PROBLEM INVESTIGATED

The experiments presented in this paper were prompted by a desire to overcome some of the difficulties encountered in the use of the hydrogen electrode for the quantitative measurements involved in the adjustment of the hydrogen-ion concentration of a soil suspension to any other desired concentration. At the same time, it was desired to study some of the phenomena associated with the adsorption of calcium when added to the soil in the form of a  $Ca(OH)_2$  solution. The time of the investigator is an important factor. To eliminate the time factor as an objection to the use of the electrometric method for soil, it is necessary to devise apparatus and methods which require the minimum amount of continuous attention.

For work on soil acidity neutral salts have been much used. A neutral salt, such as  $KCl$ , also forms a part of the electrical connection between the electrode vessel and calomel cell. For these reasons this salt was included in the work here presented. The relative solubility of the acid-producing substance was studied by making measurements on both suspensions and extracts of soils. Calcium was for the most part added in the form of a  $Ca(OH)_2$  solution. In some experiments precipitated  $CaCO_3$  was used in addition to the  $Ca(OH)_2$ .

#### METHODS OF EXPERIMENTATION

##### SPECIAL APPARATUS

The potentiometer system, essentially as outlined by Hildebrand (21) was used in this investigation. The apparatus consists of the following principal pieces: One Weston direct-reading laboratory standard voltmeter, No. 5; one Kohlrausch slide-wire bridge, one Leeds and Northrup No. 2500 type R galvanometer with lamp and scale, Edison storage batteries, and other necessary accessories. The saturated potassium chlorid-calomel cell was chosen as best suited for soil work. Fales and Mudge (12) have shown that this type is the most reliable.

An apparatus was devised by which it was possible to have six electrodes in operation at the same time, so arranged as to require very little continuous attention. The position of these electrodes with reference to one another and the wiring arrangement are shown in figure 1. A side view of one of the combinations of hydrogen electrode and calomel

cell is shown in figure 2. The frame holding the six electrode vessels is supported by an iron rod passing through a hole over the center of gravity. The electrode vessels can be shaken continuously by means of the apparatus represented in figure 3. The shaking apparatus is operated by an electric motor producing about 120 agitations per minute. The hydrogen electrode, shown in figure 4, is constructed on the same plan as Hildebrand's (21). The hydrogen was made electro-

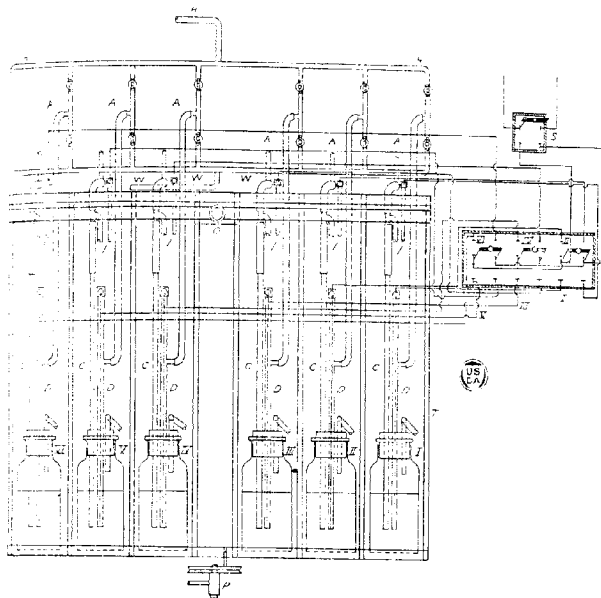


FIG. 2.—Diagram illustrating the arrangement of the electrode vessels on a supporting frame which is rotated from below by means of a pulley, thus giving the desired amount of shaking. Each pair, comprising electrode vessel and calomel cell, is wired independently and is connected to the potentiometer by means of its own switch, shown at the right, through the main switch S. The individual switches are numbered with Roman numerals, and each corresponding bottle used as electrode vessel is numbered with the same numeral. The hydrogen enters at H and is distributed to the six electrode vessels. The rate of flow to each is controlled by an ordinary glass stopcock. Water for washing the electrodes is admitted from below at W and enters the electrode through the same tube as the hydrogen.

lytically and obtained compressed in iron cylinders. It was purified in a train of saturated solution of  $\text{HgCl}_2$ , alkaline pyrogalllic acid, alkaline permanganate and distilled water.

#### SOILS AND OTHER MATERIALS USED

The general plan was to make an intensive study on one soil and then extend certain phases to other soils and other materials. Oswego silt loam was selected for the more extended study. The sample was taken in southeastern Kansas, where acid soils are more common than in the rest of the State. It contained a small amount of calcium and was moderately acid. A characteristic feature of this type of soil is the compact,

heavy subsoil. Soil samples, representing different types taken during the soil survey in various parts of the State, were available for certain phases of the work. The soils were ground in a ball mill to pass a 100-

Fig. 2.

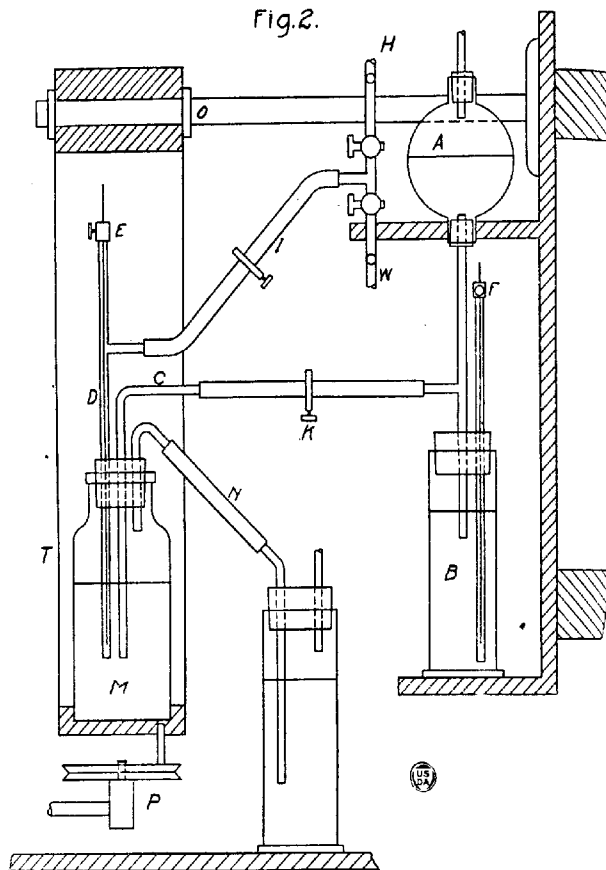


FIG. 2.—Side view of electrode vessel with calomel cell and accessories. The hydrogen enters at H, and water for washing the electrode is admitted at W from a reservoir above; thus both hydrogen and water reach the electrode through the same tube I. Water is admitted only when it is desired to wash the electrode between determinations. The hydrogen may be used to blow out the surplus water after washing. The rate of hydrogen flow is controlled by the stopcock in the tube H. A is the reservoir for the potassium chloride solution, connecting directly with the calomel cell B below and the electrode vessel M through the capillary tube C. The stopcock K can be an ungreased ordinary glass stopcock, or a Mohr's pinchcock may be used on a rubber tube. N, outlet tube for spent hydrogen, which passes through water in the bottle below. Instead of this arrangement a Bunsen valve may be used. E, wire from the hydrogen electrode. F, wire from the calomel cell. The pairs of wire go to the individual switches shown in Figure 1. O, iron rod which supports the frame holding the six electrode vessels.

mesh sieve. As all were free from fine gravel and stones this grinding did not alter the texture. Besides these soils there were used ignited soil, acid-treated soil, leached soil, and fuller's earth.

## CALCIUM HYDROXID AND WATER FOR DILUTION

The calcium hydroxid solution was made by adding distilled water to an excess of calcium oxid and allowing to settle. The titration value and calcium in a measured portion had to be determined frequently, as it was found that the concentration would change slightly on standing in contact with an excess of solid  $\text{Ca}(\text{OH})_2$ . For some of the work, solutions of definite  $\text{Ca}(\text{OH})_2$  concentrations were made. To make these was time-consuming; furthermore, it was impossible in practice to maintain a constant concentration for any considerable period of time. A more satisfactory procedure was to use a saturated  $\text{Ca}(\text{OH})_2$  solution of known strength, and to adjust the relative proportions of soil,  $\text{Ca}(\text{OH})_2$  solution and water in such a way that a definite number of cc. of the  $\text{Ca}(\text{OH})_2$  solution would represent the number of milligrams of calcium desired per 10 grams of soil.

When ordinary distilled water was used, it was purified by bubbling air free of  $\text{CO}_2$  through it for about five hours. At the end of this time 100 cc. would give a distinct color with 1 drop of 0.05N NaOH, using phenolphthalein as an indicator. For most of the work water made in a conductivity still was used.

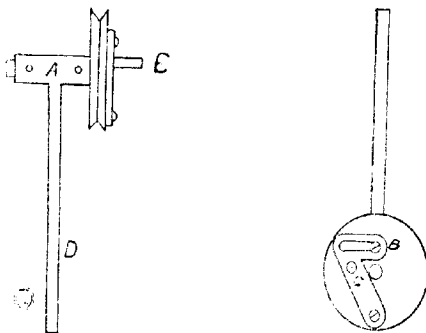


FIG. 3.—Apparatus for shaking the support for the electrode vessels. Rod D is fastened in an ordinary laboratory clamp holder. The radius of the circle described by the crank pin C can be changed by adjusting the screw at B. By this arrangement and by altering the speed of the motor, the electrode vessels can be subjected to any desired degree of shaking.

## RELATIVE AMOUNTS OF SOIL, LIQUID, AND CALCIUM

On the basis of some preliminary work, and also the work of Sharp and Hoagland (41), Plummer (37), and others, it was decided to use soil and liquid in a ratio of 1:10. The amount of soil and other materials used in the different determinations were such that the final data are on the basis of 10 grams of soil. A saturated solution of  $\text{Ca}(\text{OH})_2$  has a normality of about 0.042, but for convenience in final calculations the dilutions of the  $\text{Ca}(\text{OH})_2$  solution were calculated to the basis of 0.04N, or a definite fraction of this normality. Five cc. of 0.04N  $\text{Ca}(\text{OH})_2$  solution contain 4 mgm. of calcium, or the equivalent of 10 mgm.  $\text{CaCO}_3$ . This gives a ratio of 1:1,000 when 10 grams of soil are used, or, figuring the weight of soil 7 inches deep at 2,000,000 pounds, the equivalent of 1 ton per acre. Accordingly each cc. of 0.04N  $\text{Ca}(\text{OH})_2$  represents 400 pounds of  $\text{CaCO}_3$  per acre. In a few of the experiments, where calcium hydroxid solutions of definite concentrations were used, there is a variation from this ratio. In such instances the exact amount of calcium added per 10 grams of soil is given.



## PREPARATION OF THE SOIL SUSPENSION

Soil, water,  $\text{Ca}(\text{OH})_2$  solution, or other chemical, two or more as the particular experiment called for, were placed in 500 cc. wide-mouth bottles and closed with rubber stoppers. These were then placed on a shaking machine which had a 2-inch forward and back motion at the rate of about 90 vibrations per minute. From preliminary experiments it was found that it was best to leave the soil in contact with the  $\text{Ca}(\text{OH})_2$  for about 24 hours. Experiments in which contact existed for 48, 72, and 96 hours indicated that slight chemical changes took place after 24 hours, but so small in fact as not to interfere with the main purpose of these experiments. The usual plan was to prepare the mixtures in the afternoon, shake for an hour, let stand over night and then shake for a while the next morning. The suspensions were then transferred to 250 cc. wide-mouth bottles used as electrode vessels, and the electrometric measurements made the same day. As six of these measurements were carried on simultaneously, 12 or 18 determinations were a convenient day's work with those suspensions or extracts which attained equilibrium in the usual time.

## PREPARATION OF SOIL EXTRACTS

For the extracts 20 gm. of soil and 200 cc. of  $\text{Ca}(\text{OH})_2$  were generally used. These quantities were sufficient to produce 100 cc. of material for the titrations and calcium determinations and at least 50 cc. for the electrometric measurements. After shaking in the same manner as for making the suspensions the soil was allowed to settle. When the quantity of electrolytes present were sufficient to cause coagulation, a clear solution could be obtained by pipetting off the supernatant liquid. In other cases the contents of the bottles were transferred to 500 cc. bottles and centrifugalized for about five minutes. The centrifugal force attained was about 1,300 times gravity. A perfectly clear solution was not always obtained by this method, as some colloidal clay frequently remained in suspension. The opalescence was approximately that obtained by long-time settling of clay in water. This did not interfere with the titrations, and usually did not interfere with the calcium determinations. Some calcium silicate may have been present in colloidal suspension and may account for a small part of the calcium obtained in some extracts. The colloidal matter seemed to affect the electrometric measurements, making them more uncertain and reducing the number of times an electrode could be used before replatinizing.

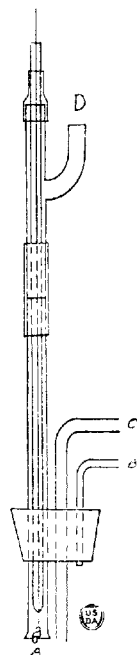


FIG. 4.—Hydrogen electrode supported in rubber stopper which fits the bottle used as electrode vessel. C, capillary glass tube making connection with the saturated potassium chloride calomel cell. B, glass tube through which excess gas may escape. The hydrogen enters at D.

## TITRATION AND CALCIUM DETERMINATION

The titrations were made by means of 0.05N HCl and 0.05N NaOH, using phenolphthalein as an indicator. The extracts were usually boiled before titrating. The maximum difference in titrating 100 cc.

of boiled or unboiled extracts was 0.2 to 0.3 cc. of the standard solution. These figures are within the limits of the error of any data used as a basis for conclusions in the present investigation. The portion used for titration was also used for the determination of calcium. The extracts were made acid with HCl and the calcium was precipitated as oxalate in the presence of  $\text{NH}_4\text{Cl}$  and sodium acetate. The oxalate was filtered on asbestos, dissolved in  $\text{H}_2\text{SO}_4$  and titrated with 0.05N  $\text{KMnO}_4$ .

#### MAKING THE ELECTROMETRIC MEASUREMENTS

Before using, the electrodes were tested by making a blank determination on a standard acetate solution (4, 35). This blank determination was made every day. Experience showed that if the electrodes were carefully washed after each determination they could be used three or four times before they needed to be replatinized. The hydrogen was bubbled through the suspensions or extracts contained in the electrode vessels, which were shaken continuously during the measurements. Readings were taken at such intervals as were found necessary, and continued till they remained constant, within 1 millivolt, for five minutes or more. Most soil suspensions or extracts did not come to an apparent equilibrium in much less than an hour, and many required a longer time. Extracts or suspensions, the reaction of which is near  $\text{P}_\text{H}$  7 come to equilibrium much more slowly than those of a higher or lower  $\text{P}_\text{H}$ . This was particularly true if  $\text{CaCO}_3$  was present. In some such cases the material required as much as five or six hours to come to equilibrium. The tables of Schmidt and Hoagland (40) were used for calculating the  $\text{P}_\text{H}$  values corresponding to the voltmeter reading, the necessary correction for the saturated calomel cell being made.

#### EXPERIMENTAL RESULTS

GROUP A.—INFLUENCE OF CALCIUM HYDROXID, CALCIUM CARBONATE, POTASSIUM CHLORID, HYDROCHLORIC ACID, AND OXALIC ACID, SINGLY OR IN COMBINATION, UPON  $\text{P}_\text{H}$  OF SUSPENSIONS AND EXTRACTS OF NATURAL SOIL; ALSO UPON THE TITRATION AND CALCIUM CONTENT OF THE EXTRACTS

##### EXPERIMENT 1.—SOIL+ WATER

It has been shown by several investigators (23, 37, 41) that the reaction obtained on a soil suspension in water is different from that obtained on a filtered extract. This difference is due to the relative insolubility of the acid-forming substance. In Table I are found the  $\text{P}_\text{H}$  values obtained on four soils, together with the titration values on 100 cc. extract and the amount of water-soluble calcium. The extracts of these four soils came to equilibrium very slowly. These extracts were not boiled before titrating, and so contain the maximum amount of  $\text{CO}_2$  likely to be present in such extracts. The amount of calcium obtained is small. This was to be expected, since the total calcium content of these soils is low.

TABLE I.—*P<sub>H</sub> on water suspensions and extracts of soils, titrations, and calcium content of extracts*

Soil type.	Suspension.	Extracts.	0.05N NaOH.	Calcium in extract.
	<i>P<sub>H</sub></i>	<i>P<sub>H</sub></i>	<i>Cc.</i>	<i>Mgm.</i>
Neosho silt loam.....	6.48	8.54	0.45	1.0
Oswego silt loam.....	5.66	8.50	.40	1.3
Bates very fine sandy loam.....	4.82	8.50	.50	.7
Bates loam.....	7.56	8.61	.50	1.9

Rice and Osugi (39) found that the suspensions of many soils would invert cane sugar, while the extracts of such soils had little or no power. Soils containing calcium in equilibrium with  $\text{HCO}_3$  and  $\text{CO}_2$  have an alkaline reaction (23).

In some cases, in connection with experiments reported in this paper, titrations were made on the water extracts used for the electrometric measurements. In such cases the hydrogen removed the  $\text{CO}_2$ , and one drop of the 0.05N NaOH would produce a color with the indicator. This means that the titrable acidity of the extracts in Table I was due to carbonic acid. The maximum error of titration in any experiment due to the presence of  $\text{CO}_2$  was therefore small, and when the  $\text{CO}_2$  was removed by boiling or by bubbling hydrogen it was nil. The slowness of attaining equilibrium when  $\text{CaCO}_3$  was present was evidently due to the slow decomposition of this substance under the conditions of the experiment.

#### EXPERIMENT 2.—SOIL + WATER + POTASSIUM CHLORIDE

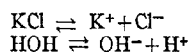
The same soils were used as in Experiment 1, but in making the suspensions and the extracts enough of a 3N KCl solution was added to make the liquid in contact with the soil 0.5N KCl. Preliminary experiments showed that it made no material difference at what point in the preparation that KCl was added. In all of the experiments where this salt was used the amount was such as to make the concentration 0.5N. The results obtained are presented in Table II.

TABLE II.—*P<sub>H</sub> on suspensions and extracts of soils made with a solution of KCl and the calcium content of the extract*

Soil type.	Suspensions.	Extracts.	Calcium in extract.
	<i>P<sub>H</sub></i>	<i>P<sub>H</sub></i>	<i>Mgm.</i>
Neosho silt loam.....	5.83	7.29	8.0
Oswego silt loam.....	5.02	6.61	14.1
Bates very fine sandy loam.....	4.51	4.95	7.0
Bates loam.....	6.48	6.97	21.5

The presence of the neutral salt, KCl, increases the hydrogen-ion concentration both in the suspensions and in the extracts. This would indicate that the acid-forming substance is more soluble in a KCl solution than in water. Sharp and Hoagland (41) found that other neutral

salts such as NaCl and BaCl<sub>2</sub> as well as KCl increased the hydrogen-ion concentration of certain soil suspensions. What happens may be pictured as follows:



The increase in hydrogen-ion concentration is due to the greater adsorptive capacity of soil for the K<sup>+</sup> and OH<sup>-</sup> ions. According to Parker (36) molecular adsorption of KOH may also take place.

It will be shown in a subsequent experiment that the amount of calcium made soluble in a 0.5N KCl solution is very nearly the same as in 0.5N HCl solution. The above equations show that it is simply a reaction of calcium with chlorinions whether the solution is made with HCl or KCl.

#### EXPERIMENT 3.—SOIL + CALCIUM CARBONATE <sup>4</sup>

Precipitated CaCO<sub>3</sub> was added in definite amounts to 10 gm. of soil. Two groups of mixtures were prepared. One group was placed in 125-cc. wide-mouthed glass-stoppered bottles, sealed, and let stand for 6 weeks, with occasional shaking. On this group the P<sub>H</sub> values were determined on the suspensions only. The other group was given the usual 24 hours contact and the P<sub>H</sub> values were determined on both the suspensions and the extracts. The results are presented in Table III.

TABLE III.—P<sub>H</sub> on water suspensions and extracts of soils to which CaCO<sub>3</sub> had been added

Calcium added.	Oswego silt loam.			Bates very fine sandy loam.		
	6 weeks.	24 hours.		6 weeks.	24 hours.	
	Suspension.	Suspension.	Extract.	Suspension.	Suspension.	Extract.
Mgm.	P <sub>H</sub>	P <sub>H</sub>	P <sub>H</sub>	P <sub>H</sub>	P <sub>H</sub>	P <sub>H</sub>
2.5 .....	7.46	6.00	6.31	7.79	5.66	6.24
5.0 .....	7.93	7.05	6.64	8.10	6.30	7.59
10.0 .....	8.10	7.83	8.34	8.10	7.79	8.23
20.0 .....	8.13	7.93	8.42	8.40	8.30	8.10
40.0 .....	8.37	8.13	8.93	8.40	8.37	8.91

Calcium added in the form of CaCO<sub>3</sub> will change the hydrogen-ion concentration of a soil suspension, and the amount of change up to a certain point is proportional to the quantity of CaCO<sub>3</sub> added. In a supplementary experiment it was found that the P<sub>H</sub> for suspensions prepared from soils to which increasing quantities of CaCO<sub>3</sub> were added would approach a maximum of about 8.50, and remain at this figure regardless of the quantity of CaCO<sub>3</sub> added, up to 20 tons equivalent per acre. When the same amount of CaCO<sub>3</sub> is added to soil, a long-time contact produces a greater hydroxyl-ion concentration than a short time. The acid-producing substance in soil liberates its hydrogen ions very slowly. It has been shown by Hagar (15) and McIntire (32, p. 41-45,) that CaCO<sub>3</sub> undergoes profound changes in soil.

<sup>4</sup>As water was used in all of the experiments in such amounts as to make the proportion of soil and liquid one, the presence of this substance is to be understood.

## EXPERIMENT 4.—SOIL+CALCIUM CARBONATE+POTASSIUM CHLORID

In this experiment KCl was added to the soil in addition to the  $\text{CaCO}_3$ , and the time of contact was 24 hours. The results for  $P_H$  titrations and calcium are presented in Table IV.

TABLE IV.— $P_H$  on suspensions and extracts of soil+ $\text{CaCO}_3$  made with a solution of KCl; also the titration and calcium content of the extracts

Calcium added.	Oswego silt loam.				Bates very fine sandy loam.			
	Suspension.	Extract.	0.05 N HCl.	Ca in extract.	Suspension.	Extract.	0.05 N HCl.	Ca in extract.
Mgm.	$P_H$	$P_H$	Cc.	Mgm.	$P_H$	$P_H$	Cc.	Mgm.
2.5.....	5.6	7.3	0.0	14.1	5.2	5.1	—0.1	8.2
5.0.....	6.0	7.6	—1	17.7	5.6	6.3	—1	9.2
10.0.....	7.1	8.3	.0	19.8	7.2	8.4	.0	13.0
20.0.....	7.5	8.4	.4	20.4	7.8	8.4	.4	18.7
40.0.....	7.6	8.5	.4	24.4	8.0	8.4	.5	19.0

When salts like KCl, NaCl and  $\text{CaCl}_2$ , each composed of a strong base and a strong acid, are added to soil the H-ion concentration of the soil suspension is increased.  $\text{CaCO}_3$  is a salt of a strong base and a weak acid. When carbonates were added to soil (Experiment 13) the H-ion concentration of the suspension was decreased. In Experiment IV the KCl increased the hydrogen-ion concentration, even in the presence of  $\text{CaCO}_3$ . The calcium in the extract was dissolved by KCl partly from the soil and partly from the added  $\text{CaCO}_3$ , but only a part of the added  $\text{CaCO}_3$  was dissolved. When 40 mgm. of calcium were added in the form of  $\text{CaCO}_3$ , the amount obtained in solution was only about 10 mgm. more than when 2.5 mgm. were added.

The titrations with 0.05N HCl were made on the same solutions in which the calcium was determined. Each cc. of this standard HCl solution is stoichiometrically equivalent to 1 milligram of calcium as a carbonate or as a hydroxid. The small values of the titer figures show that very little calcium was present in such forms. The KCl furnishes the conditions essential for changing the calcium to  $\text{CaCl}_2$  and it is probable that the calcium was present in the form of a neutral salt. The high hydroxyl-ion concentrations obtained with the larger amounts of  $\text{CaCO}_3$  were due to the presence of the ions  $\text{HCO}_3$ ,  $\text{CO}_3$ , and Ca, which are ions of a weak acid and a strong base.

## EXPERIMENT 5.—SOIL+CALCIUM HYDROXID

In this and the following experiments Oswego silt loam was used unless a statement to the contrary is made. The  $\text{Ca}(\text{OH})_2$  solution was added to the soil in increasing amounts, beginning with 2.5 mgm. and running up to 80 mgm. of calcium equivalent for 10 gm. of soil. These amounts represent from one-third ton to 20 tons equivalent of  $\text{CaCO}_3$  per acre. The results are given in Table V.

TABLE V.—*P<sub>H</sub>* on suspensions and extracts of soil + Ca(OH)<sub>2</sub>, also titrations and calcium content of extract and calcium adsorbed by soil

Calcium added.	Suspension.	Extract.	Titer 0.05N HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	P <sub>H</sub> .	P.	Cc.	Mgm.	Mgm.	Mgm.
2.5.....	6.14	8.06	—0.1	2.4	0.0	2.5
5.0.....	7.08	8.20	—1	2.3	.0	5.0
8.0.....	7.45	8.54	.0	2.0	—3	8.0
12.0.....	7.90	8.57	.4	2.3	.0	12.0
16.0.....	8.13	8.88	.4	2.7	.4	15.6
20.0.....	8.71	8.91	.5	3.7	1.4	18.6
24.0.....	9.55	9.38	.6	4.0	1.7	26.3
28.0.....	10.40	10.23	.8	4.7	2.4	33.6
32.0.....	11.07	11.00	1.6	8.0	5.7	42.3
36.0.....	11.54	11.41	3.5	13.0	10.7	49.3
40.0.....	11.85	11.71	12.6	23.3	21.0	59.0

The figures for the smaller amounts of calcium added are the averages of several determinations. The *P<sub>H</sub>* values show that the hydrogen-ion concentrations were higher in the suspensions than in the extracts until more than 16 mgm. of calcium had been added. Beyond 16 mgm. of calcium the *P<sub>H</sub>* values for suspensions and extracts were nearly equal. In these the OH-ion concentration was so large as to mask the influence of any substance dissolved from the soil. The *P<sub>H</sub>* values became equal in the suspension and the extracts when the adsorption of calcium ceased to be practically complete. This is shown in what follows.

All of the extracts to which less than 16 mgm. of calcium were added contained nearly the same amounts of calcium. This calcium may be accounted for partly by the small amount of water-soluble calcium in the soil, and partly from the re-solution of adsorbed calcium. The water-soluble calcium from the soil was 1.3 mgm. In the presence of Ca(OH)<sub>2</sub> this amount would be less. When Ca(OH)<sub>2</sub> comes in contact with soil in such a water suspension as was used in this experiment it probably forms an adsorption compound. This compound would be to some extent soluble in water (26) and would account for a larger part of the calcium in those extracts in which the adsorption was practically complete. Part of the calcium may have been present in a colloidal suspension, however, as shown by titration results; very little, if any, could have been present as a carbonate.

The average amount of calcium found in the extracts, when 16 or less mgm. were added as Ca(OH)<sub>2</sub>, was 2.3 mgm. The mgm. of the adsorbed calcium were obtained by subtracting 2.3 from the subsequent figures in the column. According to this calculation, adsorption can be considered complete until 16 or more mgm. of calcium were added and comparatively little remained unadsorbed until more than 36 mgm. were added. This shows the large adsorptive capacity of this soil for calcium when added in the form of Ca(OH)<sub>2</sub>. Since 4 mgm. represent the equivalent of 1 ton of CaCO<sub>3</sub> per acre 7 inches deep, this soil requires the equivalent of between 4 and 5 tons of CaCO<sub>3</sub> per acre to produce a *P<sub>H</sub>* value in the suspension corresponding to the color change of phenolphthalein. (See fig. 6.)

## EXPERIMENT 6.—SOIL+CALCIUM HYDROXID+POTASSIUM CHLORID

This experiment was performed like Experiment 5, with the exception that KCl was used in addition to the  $\text{Ca}(\text{OH})_2$ . The data obtained are presented in Table VI. In comparison with those in Table V, the data show clearly that the hydrogen-ion concentration was considerably increased by KCl, even when large amounts of  $\text{Ca}(\text{OH})_2$  were added. In the presence of KCl more of the hydrogen ions are liberated from the acid-forming substances, and more  $\text{Ca}(\text{OH})_2$  is required for neutralization. The absolute neutral point was passed when between 2 and 3 tons equivalent of  $\text{CaCO}_3$  per acre were added in the form of  $\text{Ca}(\text{OH})_2$ . The figures for the  $P_H$  values in Tables V and VI present some variations not easily explained, probably due to some disturbing factors not understood.

TABLE VI.— $P_H$  on suspensions and extracts of soil+ $\text{Ca}(\text{OH})_2$ +KCl, also titrations and calcium content of extract, and calcium adsorbed by soil

Calcium added.	Suspension.	Extract.	Titer 0.05N HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	Mgm.	Mgm.
0.0.....	5.02	6.61	—0.1	14.0	0.0	0.0
2.5.....	5.50	6.70	—1	15.5	1.5	1.0
5.0.....	5.70	.....	—1	16.1	2.1	3.9
8.0.....	6.46	6.71	—1	19.3	5.3	2.7
12.0.....	7.22	7.25	—1	21.1	7.1	4.9
16.0.....	7.93	7.45	—2	21.3	7.3	8.7
20.0.....	8.50	7.76	.0	23.5	9.5	10.5
28.0.....	9.32	8.10	.0	26.5	12.5	15.5
36.0.....	10.13	.....	.5	29.6	15.6	20.4
48.0.....	11.00	10.94	1.0	35.0	21.0	27.0
60.0.....	11.41	11.41	1.4	41.2	27.2	32.8

The calcium in the extract came from that dissolved from the soil by KCl and also from the added  $\text{Ca}(\text{OH})_2$ . The calcium not adsorbed was obtained by subtracting 14, the figure obtained when no  $\text{Ca}(\text{OH})_2$  was added, from each subsequent figure. The figures so calculated for unadsorbed calcium are considerably larger than the corresponding ones in Table V. When KCl is present part of the soil's capacity for adsorbing the base is satisfied, and less calcium is adsorbed. A little over half as much calcium was adsorbed in Experiment 6 as in Experiment 5. Even this amount of adsorption is large when the large excess of KCl is considered, and it shows the great capacity of the soil for adsorbing calcium. (See fig. 6.)

## EXPERIMENT 7.—SOIL+CALCIUM HYDROXID+CALCIUM CARBONATE

The amounts of precipitated  $\text{CaCO}_3$  equivalent to the calcium in the different portions of  $\text{Ca}(\text{OH})_2$  used in Experiment 5 were mixed with the various portions of dry soil. The rest of the experiment followed the method of No. 5. The data obtained are presented in Table VII. (See fig. 5.)

TABLE VII.— $P_H$  on suspensions and extracts of soil+ $\text{CaCO}_3$ + $\text{Ca}(\text{OH})_2$ , also titrations and calcium content of extract and calcium adsorbed by soil

Ca added in $\text{Ca}(\text{OH})_2$ .	Ca added in $\text{CaCO}_3$ .	Suspension.	Extract.	0.05N HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	Mgm.	Mgm.
2.5.....	2.5	7.1	7.7	—0.2	2.4	0.0	2.5
5.....	5	7.6	8.0	— .2	2.4	.0	5.0
8.....	8	7.73	8.4	.2	2.4	.0	8.0
12.....	12	7.96	8.54	.2	2.4	.0	12.0
16.....	16	8.27	8.57	.4	2.4	.0	16.0
20.....	20	8.81	8.67	1.2	2.4	.0	20.0
28.....	28	9.69	9.15	1.4	3.0	.6	27.4
36.....	36	10.46	10.43	1.5	4.6	2.2	33.8
48.....	48	11.38	11.14	4.1	8.4	6.0	42.0
60.....	60	11.55	11.53	10.4	14.3	11.9	48.1
80.....	80	11.88	11.85	20.3	25.6	23.2	56.8

The influence of the smaller quantities of  $\text{CaCO}_3$  added was apparent in the greater hydroxyl-ion concentration produced with the smaller additions of  $\text{Ca}(\text{OH})_2$  solutions. Where the larger portions of  $\text{Ca}(\text{OH})_2$  were added, the influence of the equivalent amounts of  $\text{CaCO}_3$  on the  $P_H$  values was nil. Here the excess of the hydroxyl-ions was so large as to mask completely the influence of the  $\text{HCO}_3$  and  $\text{CO}_3$  ions. The later figures show that a larger amount of calcium was present as  $\text{Ca}(\text{OH})_2$  or  $\text{CaH}_2(\text{CO}_3)_2$  than in Experiment 5, but the amounts of unadsorbed calcium in the extracts were the same. The figures for the adsorption of calcium were based on the amounts added in  $\text{Ca}(\text{OH})_2$ . According to this method of calculation as much calcium was adsorbed from  $\text{Ca}(\text{OH})_2$  when  $\text{CaCO}_3$  was present as when it was absent. It should be remembered that in the 24-hours contact, equilibrium between soil and  $\text{CaCO}_3$  had probably not been reached.

## EXPERIMENT 8.—SOIL+CALCIUM HYDROXID+CALCIUM CARBONATE+POTASSIUM CHLORID

This experiment was performed in all respects like No. 7, except that KCl was employed in the usual concentration. The data obtained are given in Table VIII. (See fig. 5.)

TABLE VIII.— $P_H$  on suspensions and extracts of soil+ $\text{CaCO}_3$ + $\text{Ca}(\text{OH})_2$ +KCl, also titrations and calcium content of extracts and calcium adsorbed by soil

Calcium added in $\text{Ca}(\text{OH})_2$ .	Calcium added in $\text{CaCO}_3$ .	Suspension.	Extract.	0.05N HCL.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	Mgm.	Mgm.
2.5.....	2.5	5.50	6.40	0.0	17.1	3.1	0.0
5.....	5	7.10	7.70	.0	19.2	5.2	.0
8.....	8	7.69	7.90	.1	21.3	7.3	.7
12.....	12	8.00	7.99	.2	21.6	7.6	4.4
16.....	16	8.10	7.96	.3	21.9	7.9	8.1
20.....	20	8.47	8.10	.5	23.8	9.8	10.2
28.....	28	9.38	8.28	.8	27.0	13.0	15.0
36.....	36	9.91	9.35	1.0	30.1	16.1	19.9
48.....	48	11.07	10.97	4.6	35.4	21.4	26.6
60.....	60	11.48	11.37	8.0	42.3	28.3	31.7



The presence of KCl was evident in the decreased number of OH ions produced by the addition of  $\text{Ca}(\text{OH})_2$ . This was true for both suspensions and extracts, and similar to results obtained in preceding experiments in which KCl was used. The figures for calcium adsorption are very similar to those obtained in Experiment 6. In the short time contact of this experiment the total effect of KCl was not influenced by the presence of  $\text{CaCO}_3$ .

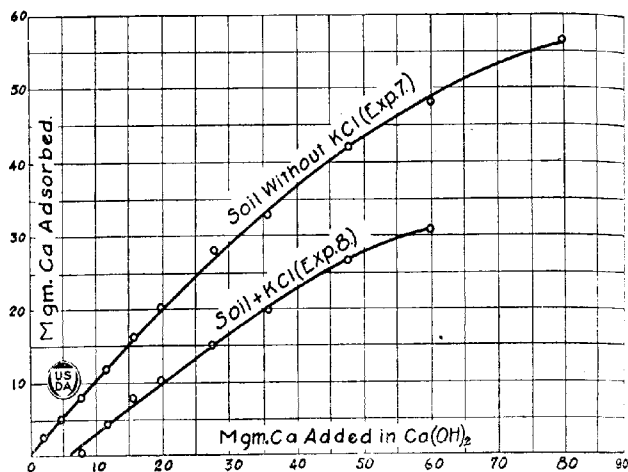


FIG. 5.—Curves showing the influence of KCl on the adsorption of Ca from  $\text{Ca}(\text{OH})_2 + \text{CaCO}_3$ .

#### EXPERIMENT 9.—SOILS + DILUTE HYDROCHLORIC ACID

In this experiment the plan was to add 0.04N HCl to three soils in portions stoichiometrically equivalent to the calcium used in several of the preceding experiments. The calculated amount of 0.04N HCl was added to the soil with enough water to make the ratio of soil and liquid 1:10. The time of shaking and the duration of the digestion was the same as in the preceding experiments. Oswego silt loam, Bates very fine sandy loam, and Bates loam were used. The data obtained are presented in Table IX.

TABLE IX.— $P_H$  on suspensions and extracts of soil+HCl, also titrations and calcium content of the extracts

HCl added.		Oswego silt loam.				Bates very fine sandy loam.				Bates loam.			
0.04N per 10 grams soil	Cu equivalent.	Suspension.	Extract.	0.05N NaOH.	Calcium in extract.	Suspension.	Extract.	0.05N NaOH.	Calcium in extract.	Suspension.	Extract.	0.05N NaOH.	Calcium in extract.
Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.
3.12	2.5	4.78	5.19	0.4	1.9	4.14	5.93	0.5	1.5	6.00	5.36	0.2	2.1
6.25	5.0	4.21	4.82	.4	3.1	3.70	4.12	.9	3.2	5.33	5.33	.2	4.1
12.5	10.0	3.16	3.76	1.0	6.4	3.23	3.09	4.5	4.0	4.58	4.65	.5	6.1
25.0	20.0	2.72	2.76	5.6	10.0	2.44	2.38	13.6	4.2	3.22	3.57	1.7	12.1
50.0	40.0	2.18	2.14	23.2	12.4	2.04	1.91	32.9	4.6	2.42	2.48	12.4	20.1

The  $P_H$  values on both suspensions and extracts showed an increase in hydrogen-ion concentration corresponding to the increased amounts of HCl added. Where the smaller amounts of HCl were added, the hydrogen-ion concentrations were greater in the suspensions than in the extracts. The same relationship between suspensions and extracts was found in the preceding experiments when small amounts of  $\text{Ca}(\text{OH})_2$  were added to soil. This was thought to be due to the relative insolubility of the acid-producing substance in soil. With HCl the added acid is soluble, and in the dilution used is completely ionized, yet the same differences in  $P_H$  were found between the suspensions and the extracts. This can be accounted for by the additive influence of the acid-forming substance in the soil suspension. The titration figures show that a portion of the HCl is neutralized or adsorbed by the soil, and the amount so used corresponds to the adsorptive capacity of the soil. The two soils which adsorbed the greatest amount of calcium (Experiment 19) also neutralized the greatest amount of HCl. Perhaps the greater portion, though not all, of the HCl was neutralized in dissolving calcium from the soil. The amount of calcium obtained in the extracts was proportional to the calcium content of the soil.

The main point shown in this experiment is that while the addition of small amounts of a highly ionized acid like HCl results in an increase in the hydrogen-ion concentration of the suspensions and the extracts, yet the influence of the acid-forming substance in the soil is also shown.

#### EXPERIMENT 10.—SOILS+OXALIC ACID

This experiment was performed in the same manner as No. 9, except that 0.04N oxalic acid was used. The data obtained are presented in Table X.

There was a notable difference in the  $P_H$  values obtained with the use of oxalic acid as compared with HCl. The addition of the three smaller portions of oxalic acid produced a decrease in the hydrogen-ion concentration, while the two larger portions caused an increase. This means that the addition of a small amount of oxalic acid produces an actual increase in the hydroxyl-ion concentration. The hydrogen-ion concentration produced by 50 cc. of 0.04N oxalic acid is not as great as that produced by the same amount of 0.04N HCl (Experiment 9). This is due simply to the smaller ionization of oxalic acid, and also to the formation of insoluble oxalates.

The titration figures show the expected gradual increase as the amount of acid added to the soil increased, and the figures for oxalic acid are larger than they are for HCl. Owing to the smaller solubility of calcium in oxalic acid, the amount of calcium obtained was less when oxalic acid was used than with HCl.

TABLE X.— $P_H$  on suspensions and extracts of soil + oxalic acid; also titrations and calcium content of the extracts

H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> added.		Oswego silt loam.				Bates very fine sandy loam.				Bates loam.			
		Ca equivalent.		0.05N NaOH.		0.05N NaOH.		Calcium in extract.		0.05N NaOH.		Calcium in extract.	
cc. 0.01N per 10 gm. soil.		Suspension.	Extract.	Suspension.	Extract.	Suspension.	Extract.	Suspension.	Extract.	Suspension.	Extract.	Suspension.	Extract.
Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.
3.12	2.5	4.95	5.80	1.5	0.8	5.39	8.00	1.8	0.7	7.95	8.37	0.4	3.6
3.25	5.0	5.43	7.83	2.9	1.2	.....	7.93	4.1	1.7	8.15	8.03	1.0	3.4
12.5	10.0	7.22	7.83	7.3	2.1	5.80	8.23	8.1	1.1	8.27	8.00	2.4	3.4
25.0	20.0	5.46	4.07	12.6	3.2	3.76	3.20	17.0	1.7	7.42	7.90	8.1	4.6
50.0	40.0	3.86	2.42	31.0	4.9	2.48	2.55	35.9	2.1	5.73	3.30	21.8	6.8

The increase in the hydroxyl-ion concentration with the smaller amounts of oxalic acid can be accounted for by the fact that a salt of a weak acid and a strong base has an alkaline reaction in a water solution. This is due to the formation of the highly ionized hydroxide of the base and the feebly ionized acid. The hydrogen ions and the hydroxyl ions come from the water. When oxalic acid is added to soil, oxalates are formed. If the quantity added to soil is small these oxalates are in excess, and there are more hydroxyl-ions than hydrogen ions. When larger amounts of oxalic acid are added the reverse condition occurs. The initial reaction and the calcium content of the soil appear to determine the amount of oxalic acid required to produce an excess of hydrogen ions. With Bates loam, a neutral soil with a relative higher calcium content, the excess of the hydroxyl ions persists for a larger amount of oxalic acid than is the case with the other two soils.

When NaOH is added to the extract a part is used in basic exchange with the oxalates and part to neutralize the free oxalic acid. Bates loam neutralized a larger portion of oxalic acid than the other two soils. This soil has more calcium, and therefore more insoluble calcium oxalate could be formed. This would appear to indicate that the quantity of an organic acid, such as oxalic, which a soil is able to neutralize is a measure of the potential alkalinity.

The effect of oxalic acid on soil, as shown in this experiment, explains a fact well known to agriculturists, namely, that barnyard manure reduces the acid condition of the soil. The acids which result from the decay of organic matter combine with the bases of the soil, forming salts of weak acids and strong bases. The effect of adding organic acids to soil deserves further study, particularly those which form soluble compounds, such as acetic acid.

#### GROUP B.—INFLUENCE OF CALCIUM HYDROXID AND POTASSIUM CHLORID ON THE $P_H$ WHEN USED ON WASHED SOIL, IGNITED SOIL, ACID-TREATED SOIL, AND ACID-TREATED SAND, ALSO ON THE TITRATION AND CALCIUM CONTENT OF THE EXTRACT

##### EXPERIMENT II.—WASHED SOIL + CALCIUM HYDROXID

In this experiment  $\text{Ca}(\text{OH})_2$  was added to washed soil in the same manner as in Experiment 5. In washing, part of the colloidal clay was removed. The method of washing was as follows: One kgm. of soil was

placed in a tall 8-liter bottle, and distilled  $\text{CO}_2$ -free water added until the bottle was nearly full. The bottle was then shaken for one hour, after which the soil was allowed to settle for one week. The supernatant liquid, still turbid with colloidal clay, was siphoned off without disturbing the soil in the bottom. The bottle was again filled with water and the process of shaking, settling, and removal of supernatant liquid repeated 12 times in as many weeks. As far as could be observed, the supernatant liquid was as turbid the last time it was siphoned off as it was the first time. The soil was transferred, using a small amount of water, to 1-gallon earthenware jars, and allowed to evaporate and dry completely at room temperature. Oswego silt loam, Bates very fine sandy loam, and Bates loam were thus treated. The resulting dry soil was very friable and loose. Determinations showed that only a small percentage of the soil had been removed as colloidal matter in the washing process.

In a preliminary trial  $\text{Ca}(\text{OH})_2$  was added in varying amounts to the three washed soils, but the differences in the data from the washed soils as compared with those from the untreated were relatively the same for the three soils. Table XI gives the results obtained on the Oswego silt loam.

TABLE XI.— $P_H$  of suspensions and extracts of washed soil +  $\text{Ca}(\text{OH})_2$ ; also titrations and calcium content of extracts, and calcium adsorbed from  $\text{Ca}(\text{OH})_2$

Calcium added.	Suspension.	Extract.	0.05N. HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$ .	$P_H$ .	Cc.	Mgm.	Mgm.	Mgm.
0.0.....	4.89	7.32	0.0	0.4	0.0	0.0
2.5.....	5.94	7.35	.1	.5	.1	2.4
5.0.....	6.07	8.03	.1	.7	.3	4.7
8.0.....	6.14	7.76	.2	1.1	.7	7.3
12.0.....	7.19	8.13	.3	1.4	1.0	11.0
16.0.....	7.62	8.47	.3	1.6	1.2	14.8
20.0.....	8.03	8.30	.2	1.7	1.3	18.7
28.0.....	8.04	8.34	.4	2.6	2.2	25.8
36.0.....	9.09	9.59	1.5	4.4	4.0	32.0
48.0.....	10.87	10.40	2.5	5.3	4.9	43.1
60.0.....	11.24	11.34	9.5	14.1	13.7	46.3
80.0.....	11.68	11.68	22.8	27.1	26.7	53.3

Comparing the figures of Table XI with those in Table V it will at once be apparent that the hydrogen-ion concentrations obtained, when different amounts of  $\text{Ca}(\text{OH})_2$  were added to the soil, were greater for the washed soil than for the untreated. This means that the washing process increased the solubility of the acid-producing substance. Since the acid-producing substance is slightly soluble, a small amount was removed in the washing process. However, this removal resulted in an increase, rather than a decrease, in the hydrogen-ion concentration of the suspensions and the extracts. This indicates a continuous and increasing solubility of the acid-producing substance. (See fig. 6.)

The differences in the figures for calcium adsorption obtained on the washed soil as compared with the untreated are practically within the limits of the experimental error. If there is any real difference, washing has decreased the adsorptive capacity of soil for calcium. This was probably due to the removal of colloidal clay.

## EXPERIMENT 12.—IGNITED SOIL+CALCIUM HYDROXIDE

In this experiment  $\text{Ca}(\text{OH})_2$  was added to Oswego silt loam after it had been ignited. Weighed portions of soil as needed for the separate determinations were placed in flat-bottomed porcelain dishes and heated at  $650^\circ$  for five hours in an electric muffle having an automatic tem-

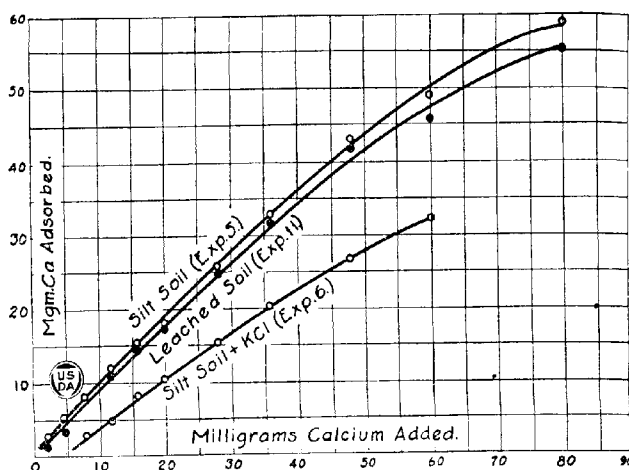


FIG. 6.—Curves showing the influence of KCl on the adsorption of calcium from  $\text{Ca}(\text{OH})_2$ .

perature control. After cooling, the ignited soil portions were transferred to bottles, and the subsequent treatment was the same as in Experiment 5. The loss on ignition as determined on one set of samples was nearly 5 per cent. The data obtained are presented in Table XII.

TABLE XII.— $P_H$  of suspensions and extracts of ignited soil+ $\text{Ca}(\text{OH})_2$ , titrations and calcium content of extracts, and calcium adsorbed from  $\text{Ca}(\text{OH})_2$

Calcium added.	Suspension.	Extract.	0.00N. HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$	$P_H$	Cc.	Mgm.	Mgm.	Mgm.
0.....	5.56	7.83	0.0	1.2	0.0	0.0
4.....	6.78	7.96	.4	2.4	1.2	2.8
8.....	8.20	8.84	.6	3.0	1.8	6.7
12.....	9.42	9.48	.9	4.2	3.0	9.0
16.....	9.99	10.60	2.5	8.9	7.7	8.5
20.....	10.40	10.97	2.7	9.2	8.0	12.0
28.....	11.97	11.17	3.4	10.0	8.8	19.2
36.....	11.34	11.58	6.5	15.2	14.0	22.0
48.....	11.61	11.85	16.7	24.0	22.8	25.2
60.....	11.68	11.90	24.2	33.3	32.1	27.9
80.....	11.87	12.01	27.4	40.5	39.3	40.7

The hydrogen-ion concentration of the suspension of the ignited soil was very nearly the same as that obtained on the original soil in Experiment 5. This shows that the acid-producing substance was not destroyed by ignition. The hydrogen-ion concentration of the extract from the ignited soil was greater than it was in the original soil. This indicates that ignition increased the solubility of the acid-producing substance. However, the addition of the same quantities of  $\text{Ca}(\text{OH})_2$  to the ignited soil produced a greater increase in the hydroxyl-ion concentration. This was due to the decreased adsorption of calcium. The amount of calcium adsorbed by the ignited soil was approximately two-thirds that adsorbed by the original soil. The adsorptive capacity was lessened by the destruction of colloidal structure brought about by ignition. It is also possible that ignition alters the structure of the silicates in such a way that less chemical combination with calcium is possible. It is recognized that a too general statement can not be based on this experiment with only one soil. However, it is clear that while the hydrogen-ion concentration was not decreased by ignition, the adsorptive power for calcium was materially decreased.

EXPERIMENT 13.—IGNITED SOIL+CALCIUM HYDROXID+POTASSIUM CHLORID

The manner of procedure in this experiment was the same as in Experiment 12 except that KCl was added. The results obtained are presented in Table XIII. The effect of KCl in increasing the hydrogen-ion concentration and decreasing the amount of calcium adsorbed was relatively the same on ignited soil as on the untreated soil. Ignition, however, decreased the solubility of calcium in a solution of KCl. In the original soil a solution of KCl dissolved 14 mgm. calcium per 10 gm. of soil, but in the ignited soil the amount dissolved was only 3.9 mgm. Thus while ignition increased the solubility of the acid-producing substances in a solution of KCl it decreased the solubility of calcium in the same solution. Preceding experiments have shown that calcium adsorption was decreased by the presence of KCl and also by ignition. This experiment shows that KCl added to the ignited soil results in a further decrease of calcium adsorption. This apparently means that while basic exchange took place less readily in the ignited soil, the substances formed were more highly ionized.

TABLE XIII.— $P_H$  suspensions and extracts of ignited soil+ $\text{Ca}(\text{OH})_2$ +KCl, also titrations and calcium content of extracts and calcium adsorbed from  $\text{Ca}(\text{OH})_2$

Calcium added.	Suspension.	Extract.	0.05N HCl	Calcium in Extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$	$P_H$	Cc.	Mgm.	Mgm.	Mgm.
0.....	4.82	5.83	0.3	3.9	0.0	0.0
4.....	6.17	7.00	.0	6.9	3.0	1.0
8.....	7.76	7.59	.4	9.7	6.8	1.2
12.....	8.88	9.18	1.3	12.3	8.4	3.6
16.....	10.05	10.02	2.9	14.7	10.8	5.2
20.....	10.43	11.03	7.6	17.5	13.6	6.4
24.....	10.90	11.20	9.6	21.8	17.9	10.1
28.....	11.14	11.51	13.8	27.1	23.2	12.8
32.....	11.44	11.61	17.2	32.1	28.2	19.8
36.....	11.68	11.95	30.1	42.6	38.7	21.5

## EXPERIMENT 14.—ACID-TREATED SOIL+CALCIUM HYDROXID. (SOIL LOW IN CALCIUM.)

One hundred gm. of soil, Oswego silt loam, were placed in a 2-liter glass-stoppered bottle and 2 liters 0.5N HCl added. The bottle was shaken for a while, and the contents were then allowed to digest for several days with occasional shakings. The soil was washed by decantation as long as it would settle clear, and finally washed on a Buchner funnel until the filtrate gave a neutral reaction to litmus. The soil was then dried and used in a manner similar to that of Experiment 5. The data obtained are given in Table XIV.

TABLE XIV.— $P_H$  of suspensions of acid-treated soil+ $\text{Ca}(\text{OH})_2$ , also titrations and calcium content of extracts and calcium adsorbed from soil. (Soil low in calcium.)

Calcium added.	Suspension.	0.05N HCL.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$	Cc.	Mgm.	Mgm.	Mgm.
8.....	3.70	-1.3	1.0	1.0	7.0
16.....	4.85	-.6	1.2	1.2	14.8
24.....	6.24	.0	2.8	2.8	21.2
36.....	7.35	.4	3.4	3.4	32.6
48.....	8.98	.6	4.5	4.5	43.5
60.....	9.42	2.3	8.1	8.1	51.9
80.....	9.72	3.4	10.8	10.8	69.2

The acid treatment greatly increased the hydrogen-ion concentration of the suspension. The small value of the titration figures in comparison with the figures for the amount of calcium in the extract indicates that most of the calcium was present in the form of a neutral compound. The ratio of the amount of calcium adsorbed in relation to the amount added was as great with an addition of 80 mgm. calcium in the form of  $\text{Ca}(\text{OH})_2$  as with 8 mgm., indicating that the adsorptive capacity was not reached. In view of this, the greater amount of calcium found in the extract was probably due to resolution of an adsorption compound of calcium.

## EXPERIMENT 15.—ACID-TREATED SOIL+CALCIUM HYDROXID. (SOIL HIGH IN CALCIUM.)

The procedure in this experiment was the same as that in Experiment 14, except that the soil used was a Summit silt loam high in calcium. The data obtained are given in Table XV.

TABLE XV.— $P_H$  of suspensions from acid-treated soil, also titrations and calcium content of extracts and calcium adsorbed from  $\text{Ca}(\text{OH})_2$ 

Calcium added.	Suspension.	0.05NHCL	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$	Cc.	Mgm.	Mgm.	Mgm.
8.....	3.36	-1.6	0.7	0.7	7.3
16.....	3.43	-1.0	1.0	1.0	15.0
24.....	3.80	-1.2	1.2	1.2	22.8
36.....	4.31	-1.0	1.8	1.8	34.2
48.....	5.77	-.4	2.1	2.1	45.9
60.....	7.35	-.4	5.1	5.1	54.9
80.....	8.47	-.5	8.8	8.8	71.2

The hydrogen-ion concentrations were greater than those in the previous experiment and were due, as shown by the titration figures, to the larger amount of free acid present. After the acid treatment this soil was more colloidal than the one the used in Experiment 14. The calcium adsorptive capacity was nearly the same in the two soils. The acid treatment may be considered a case of intense leaching. Under humid climatic conditions soils high in calcium will ultimately lose their calcium to such an extent that they are as much in need of calcium as some soils derived from acidic rocks.

#### EXPERIMENT 16.—ACID TREATED SAND+CALCIUM HYDROXID

Ordinary river sand was chosen for this experiment. It was first ground to an impalpable powder in a ball mill, then digested in HCl. Further treatment was similar to that of the two preceding experiments. The data obtained are given in Table XVI.

TABLE XVI.— $P_H$  of suspensions of acid-treated sand+ $Ca(OH)_2$  also titrations and calcium on the extract, and calcium adsorbed from  $Ca(OH)_2$

Calcium added.	Suspension.	0.05NHCl	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
Mgm.	$P_H$ .	Cc.	Mgm.	Mgm.	Mgm.
2.....	7.76	-0.3	0.8	0.8	1.6
4.....	8.03	-1.1	1.4	1.4	2.6
6.....	8.40	.6	1.9	1.9	4.1
8.....	8.50	1.6	2.5	2.5	5.5
12.....	8.84	2.2	3.7	3.7	8.3
16.....	9.25	3.9	5.2	5.2	10.8
18.....	9.35	4.7	6.5	6.5	13.5

As compared with soil, sand requires a much smaller amount of  $Ca(OH)_2$  to produce a corresponding change in the hydrogen-ion concentration. Beyond the addition of 6 mgm. calcium the titration figures together with the  $P_H$  values show that the greater part of the calcium in the extract was present as  $Ca(OH)_2$ . A small part may have been present as  $CaCl_2$ . While the amount of calcium adsorbed was much less than that obtained with soil, the ratio adsorbed to the amount added was large. Finely ground sand does adsorb calcium, and the ratio between the amount adsorbed and the amount added corresponds to the adsorption law.

#### GROUP C.—INFLUENCE OF CALCIUM HYDROXID AND POTASSIUM CHLORID ON $P_H$ WHEN USED WITH FULLER'S EARTH, ALSO ON THE TITRATION AND THE CALCIUM CONTENT OF THE EXTRACTS

##### EXPERIMENT 17.—FULLER'S EARTH+CALCIUM HYDROXID

The fuller's earth used in this experiment was a white commercial product labeled "chemically pure." It was treated like the soil in Experiment 5. The data based on 10 grams of material are given in Table XVII.



TABLE XVII.— $P_H$  of suspensions and extracts of fuller's earth, also titrations and calcium content of extracts, and calcium adsorbed from  $\text{Ca}(\text{OH})_2$ 

Calcium added.	Suspension.	Extract.	Titer 0.05N HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
<i>Mgm.</i>	$P_H$	$P_H$	<i>Cc.</i>	<i>Mgm.</i>	<i>Mgm.</i>	<i>Mgm.</i>
0.....	4.82	6.23	—0.1	4.4	0.0	0.0
4.....	7.08	7.62	.1	5.2	.8	3.2
8.....	7.76	7.76	.2	7.0	2.6	5.4
12.....	8.17	7.86	.2	8.0	3.6	8.4
16.....	8.37	8.00	.2	8.2	3.8	12.2
20.....	8.61	8.27	.4	8.8	4.4	15.6
28.....	8.91	8.57	.6	9.6	5.2	22.8
36.....	9.11	9.11	1.8	11.1	6.7	29.3
48.....	9.28	9.31	2.5	11.8	7.4	40.6
60.....	9.48	9.45	2.9	12.3	7.9	52.1

The  $P_H$  values obtained on the water suspension and the water extract of fuller's earth show that the hydrogen-ion concentration in both was greater than that obtained in an extract of soil, and, like the soil, that the hydrogen-ion concentration was greater in the suspension than in the extract. The acid-forming substance in fuller's earth was more soluble than it was in soil. This means a greater intensity of acidity in the former. The fuller's earth had a comparatively large amount of calcium in the water extract, which makes it difficult to calculate calcium adsorption except relatively. Since the ratio of the amount of calcium adsorbed to the amount added was as great with the largest as with the smallest quantity added, the adsorptive capacity was probably not reached. The adsorptive capacity of fuller's earth for calcium was greater than that of Oswego silt loam. The titration figures show that a comparatively small amount of calcium was present in the extract as hydroxid or carbonate. Some may have been present as a silicate in colloidal form, some as the soluble compound formed with the acid-forming substance in fuller's earth, and some as redissolved from the adsorption compound.

The reactions of fuller's earth with  $\text{Ca}(\text{OH})_2$  were found to be very similar to those of soil, except in degree. The acid-forming substance in fuller's earth is probably an aluminum silicate, and by inference it might be concluded that the acid-forming substance in soil is of a similar nature.

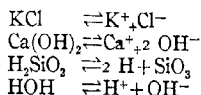
#### EXPERIMENT 18.—FULLER'S EARTH+CALCIUM HYDROXID+POTASSIUM CHLORID

This experiment was conducted in the same manner as Experiment 17, except that KCl was also added. The data obtained are given in Table XVIII.

TABLE XVIII.— $P_H$  on suspensions and extracts of fuller's earth+ $\text{Ca}(\text{OH})_2$ +KCl, also titration and calcium content of extracts, and calcium adsorbed from  $\text{Ca}(\text{OH})_2$ 

Calcium added.	Suspension.	Extract.	Titer 0.05N HCl.	Calcium in extract.	Calcium not adsorbed.	Calcium adsorbed.
<i>Mgm.</i>	$P_H$	$P_H$	<i>Cc.</i>	<i>Mgm.</i>	<i>Mgm.</i>	<i>Mgm.</i>
0.....	5.06	5.43	0.00	1.8	0.0	0.0
4.....	6.68	.....	.00	6.0	4.2	.0
8.....	7.15	7.25	.15	9.9	8.1	.0
12.....	7.66	7.62	.15	13.5	11.7	.3
16.....	8.06	7.90	.25	17.1	15.3	.7
20.....	8.27	8.06	.35	20.5	18.7	2.3
28.....	8.54	8.34	.65	25.5	23.7	4.3
36.....	8.94	8.67	1.35	29.1	27.3	8.7
48.....	9.21	9.15	1.65	33.0	31.2	16.8
60.....	9.35	9.21	2.80	35.8	34.0	26.0

In the presence of KCl corresponding amounts of  $\text{Ca}(\text{OH})_2$  produced a smaller decrease in the hydrogen-ion concentration, indicating that the solubility and the ionization of the acid-forming substance in fuller's earth are increased by KCl; in other words, there are more hydrogen ions to be neutralized by the hydroxyl ions from  $\text{Ca}(\text{OH})_2$ . On the other hand, in the presence of KCl calcium adsorption was entirely inhibited when small amounts of  $\text{Ca}(\text{OH})_2$  were added, and greatly reduced with the larger amounts. The adsorption of considerable quantities of calcium when the larger amounts of  $\text{Ca}(\text{OH})_2$  were added shows that the tendency of the calcium ions to combine with the radical of the acid-forming substance was not prevented by a large excess of K ions. One hundred cc. of a 0.5N solution of KCl contain nearly 2,000 mgm. of potassium, and yet adsorption of calcium took place when from 20 to 60 mgm. were added in the form of  $\text{Ca}(\text{OH})_2$ . The net result of the presence of KCl was a greater hydrogen-ion concentration and larger amount of unadsorbed calcium. If the acid-forming substance produces a silicic acid the following ions are present:



If this represents the ionic condition, the neutralization is due to the hydroxyl ions from  $\text{Ca}(\text{OH})_2$  combining with the hydrogen ions of the acid-forming substance. From this standpoint the reaction can be considered purely chemical. The potassium ions combine with the radicals of the acid-forming substance, producing a potassium compound. In the absence of KCl, as in Experiment 13, or when large amounts of calcium are added, as in this experiment, calcium ions combine with the radicals of the acid-forming substance. Larger amounts of calcium combine in the absence of KCl, and the ratio between the amount which combines and the amount added accords with the law of adsorption.

GROUP D.—COMPARISON OF VARIOUS SOILS IN RESPECT TO THE INFLUENCE OF CALCIUM CARBONATE, CALCIUM HYDROXID, AND POTASSIUM CHLORID UPON THE  $P_H$ , THE ADSORPTIVE POWER OF SOIL FOR CALCIUM FROM CALCIUM HYDROXID, AND THE CALCIUM SOLUBLE IN HYDROCHLORIC ACID AND POTASSIUM CHLORID SOLUTIONS

EXPERIMENT 19.—COMPARATIVE POWER OF FOUR SOILS TO ADSORB CALCIUM FROM CALCIUM HYDROXID

The purpose of this experiment was to compare the calcium-adsorptive power of four soils. Neosho silt loam, Bates very fine sandy loam, Oswego silt loam, and Bates loam were used. Eight different solutions of  $\text{Ca}(\text{OH})_2$  were made and added to soil in different definite amounts. After the usual treatment, the unadsorbed calcium and also the  $P_H$  values were determined on the extracts. The data obtained based on 10 gm. of soil are given in Table XIX.

The Bates loam, a neutral soil, and Oswego silt loam, a moderately acid soil, both containing larger amounts of clay than the other two, adsorbed nearly the same amount of calcium. Neosho silt loam, less acid than Oswego silt loam, adsorbed the least. The outstanding physical property of this soil is its small amount of clay and large amount of silt.

The Bates very fine sandy loam adsorbed more than the Neosho silt loam, but less than the other two. This soil had the highest hydrogen-ion concentration of the four, but it contains a comparatively small

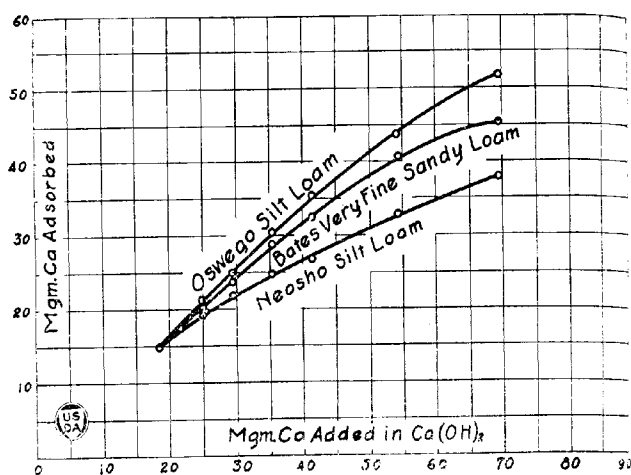


FIG. 7.—Comparative adsorption of calcium in soils (Experiment 19).

amount of clay. The main fact shown by this experiment is that the amount of clay is a factor of greater moment in calcium adsorption than is the initial intensity of acidity.

TABLE XIX.—Adsorption of calcium from  $\text{Ca(OH)}_2$  by four soils

Calcium added.	NEOSHO SILT LOAM.			OSWEGO SILT LOAM.		
	Calcium in extract.	Calcium adsorbed.	Extract.	Calcium in extract.	Calcium adsorbed.	Extract.
Mgm.	Mgm.	Mgm.	P <sub>H</sub> .	Mgm.	Mgm.	P <sub>H</sub> .
18.7	3.4	15.3	9.43	3.4	15.3	8.5
21.8	4.3	17.5	10.04	3.9	17.9	8.5
25.2	5.6	19.6	10.55	3.6	21.6	8.5
29.1	7.1	22.0	10.79	4.0	25.1	8.7
35.4	10.4	25.0	11.26	4.8	30.6	9.0
41.5	14.2	27.3	11.50	6.1	35.4	10.0
54.5	21.2	33.3	11.73	10.5	44.0	10.8
69.1	31.0	38.1	11.90	17.2	51.9	11.1
BATES VERY FINE SANDY LOAM.				BATES LOAM.		
18.7	3.8	14.9	8.52	3.8	14.9	8.2
21.8	4.0	17.8	8.55	3.9	17.9	8.3
25.2	4.3	20.9	8.66	4.3	20.9	8.5
29.1	4.7	24.4	9.67	4.6	24.5	8.7
35.4	6.4	29.0	10.41	5.3	30.1	9.0
41.5	9.0	32.5	10.95	6.6	34.9	10.0
54.5	13.8	40.7	11.30	9.1	45.4	10.8
69.1	23.9	45.2	11.73	14.5	54.6	10.9

EXPERIMENT 20.—COMPARATIVE POWER OF FOUR SOILS TO ADSORB CALCIUM FROM CALCIUM HYDROXID IN THE PRESENCE OF CALCIUM CARBONATE

The amounts of  $\text{CaCO}_3$  equivalent to the calcium adsorbed in Experiment 19 were calculated and added to the dry soil. Fifty cubic centimeters of water was added to each bottle, the mixtures shaken for several hours, and then allowed to digest for one day.  $\text{Ca}(\text{OH})_2$  solutions were next added, and from this point on the experiment was performed like No. 19. The  $\text{Ca}(\text{OH})_2$  solutions were so adjusted that very nearly the same amounts of calcium were used per 10 gm. of soil as in the preceding experiment. The data obtained are presented in Table XX. The calcium adsorbed was calculated on the basis of the amounts added in the  $\text{Ca}(\text{OH})_2$  solutions.

TABLE XX.—Adsorption by four soils in the presence of  $\text{CaCO}_3$  of calcium from  $\text{Ca}(\text{OH})_2$

$\text{Ca}(\text{OH})_2$	NEOSHO SILT LOAM.			OSWEGO SILT LOAM.		
	Calcium in extract.	Calcium adsorbed from $\text{Ca}(\text{OH})_2$	Extract.	Calcium in extract.	Calcium adsorbed from $\text{Ca}(\text{OH})_2$	Extract.
Mgm.	Mgm.	Mgm.	$P_H$ .	Mgm.	Mgm.	$P_H$ .
17.9.....	3.6	14.3	9.53	4.6	13.3	8.62
21.3.....	4.2	17.1	10.11	4.2	17.1	8.75
25.4.....	6.0	19.4	10.72	4.2	21.2	9.18
27.9.....	7.0	20.9	10.95	4.7	23.2	9.64
34.2.....	10.9	23.3	11.40	5.2	29.0	10.55
40.9.....	14.5	26.4	11.53	6.8	34.1	10.97
50.3.....	20.3	30.0	11.66	10.4	39.9	10.36
68.2.....	31.9	36.3	11.90	17.2	51.0	11.70
	BATES VERY FINE SANDY LOAM.			BATES LOAM.		
	Calcium in extract.	Calcium adsorbed from $\text{Ca}(\text{OH})_2$	Extract.	Calcium in extract.	Calcium adsorbed from $\text{Ca}(\text{OH})_2$	Extract.
Mgm.	Mgm.	Mgm.	$P_H$ .	Mgm.	Mgm.	$P_H$ .
17.9.....	4.0	13.9	8.45	5.4	12.5	8.72
21.3.....	4.7	16.6	9.37	5.0	15.7	8.77
25.4.....	4.8	20.6	9.72	5.4	20.0	9.18
27.9.....	5.7	22.2	10.06	5.4	22.5	9.21
34.2.....	7.6	26.6	10.97	5.6	28.6	10.70
40.9.....	10.0	30.9	11.22	6.5	34.4	9.60
50.3.....	15.1	35.2	11.53	9.4	40.9	11.17
68.2.....	26.0	42.2	11.80	17.3	50.9	11.63

The  $P_H$  values were not materially affected by the presence of  $\text{CaCO}_3$ . The excess of the hydroxyl ions was so large as to mask the influence of the  $\text{HCO}_3$  and  $\text{CO}_3$  ions. The addition of  $\text{CaCO}_3$  under the conditions of this experiment did not change the relative adsorptive power of these four soils as found in Experiment 19. The presence of  $\text{CaCO}_3$  only slightly reduced the amount of calcium adsorbed from  $\text{Ca}(\text{OH})_2$ . In Experiment 7 it was found that  $\text{CaCO}_3$  had practically no effect on calcium adsorption from  $\text{Ca}(\text{OH})_2$ . The only difference in procedure between Experiments 7 and 20 was that in the latter case there was a longer contact for the  $\text{CaCO}_3$  in the presence of water. While the effect of this longer contact was small it is enough to suggest that calcium is taken very slowly from  $\text{CaCO}_3$  by the soil. The effect of long-time contact with  $\text{CaCO}_3$  was also shown in Experiment 3.

EXPERIMENT 21.—THE H-ION CONCENTRATION OF SUSPENSIONS OF SOIL IN WATER AND IN A SOLUTION OF POTASSIUM CHLORID AND THE CALCIUM CONTENT OF HYDROCHLORIC ACID SOLUTIONS

In several preceding experiments it has been shown that the presence of KCl materially changes the  $P_H$  value of both soil suspensions and soil extracts. One of the difficulties encountered in making electrometric measurements on a soil suspension or extract is the possible diffusion of KCl from the contact tube. This is enhanced by the necessity of constant agitation of the electrode vessel and the long time required for making some of the measurements. It was desired to learn how serious a factor this is with different soils of varying calcium content.

Twenty-four soils with accompanying subsoils, taken in the soil survey from various parts of Kansas, were selected for this experiment. These soils had been analyzed for total calcium as well as other nutrients, and the resulting data as well as physical texture, as far as that is revealed by soil type, formed the basis of selection. The calcium soluble in cold 0.5N HCl was determined by digesting the soil at room temperature for 24 hours. The  $P_H$  values were determined both on the water suspensions and on the suspensions in the 0.5N KCl solution. Before taking the final voltmeter reading the rubber tube connecting the KCl solution reservoir and the capillary tube was opened slightly by pressing the pinchcock, so as to make fresh contact. This would introduce a small amount of KCl into the soil suspensions. Preliminary experiments had shown that the concentration of the KCl solution used as a solvent could be varied considerably without affecting the  $P_H$  values. The small quantity introduced by the manipulation just described would then have no effect on the suspension in which 0.5N KCl was used, but it might materially affect the water suspensions. It had been noticed several times in the preceding experiments that some of the soil colloidal matter would diffuse into the capillary KCl connecting tube. Just how much this influenced the reading was not known. When a KCl solution forms a part of the electrical connection with the calomel cell it is impossible to prevent some KCl entering the electrode vessel. If the system is so arranged that KCl forms part of the mixture in the electrode vessel the small quantity of KCl entering from this source may safely be ignored. The  $P_H$  values and the data on acid soluble calcium are given in Table XXI.

TABLE XXI.—Hydrogen-ion concentration and calcium content of soil and subsoil

Soil No.	County.	Soil type.	Surface.			Subsoil.		
			Cal- cium in HCl solu- tion.	H <sub>2</sub> O sus- pen- sion.	KCl sus- pen- sion.	Cal- cium in HCl solu- tion.	H <sub>2</sub> O sus- pen- sion.	KCl sus- pen- sion.
			Mgm.	$P_H$ .	$P_H$ .	Mgm.	$P_H$ .	$P_H$ .
31	Allen.....	Oswego fine sandy loam.	15.1	4.82	4.82	21.1	5.22	5.22
27	.....do.....	Oswego clay.....	34.8	5.02	4.82	50.4	5.77	5.53
23	.....do.....	Neosho silt loam...	17.3	5.09	5.06	36.4	5.66	5.53
25	.....do.....	Osage loam.....	26.1	5.09	5.06	28.2	5.43	5.50
49	Montgomery...	Crawford loam.....	18.4	5.12	4.82	25.0	5.80	5.60
11	Allen.....	Summit silt loam...	35.1	5.16	5.06	189.6	7.46	7.63
17	Brown.....	Marshall silt loam...	31.3	5.26	5.46	37.3	5.33	5.09
33	Allen.....	Summit silt loam...	18.0	5.33	5.46	16.7	4.65	4.72
15	Riley.....	Oswego silt loam...	33.0	5.39	5.33	74.0	7.16	7.12

TABLE XXI.—*Hydrogen-ion concentration and calcium content of soil and subsoil—Con.*

Soil No.	County.	Soil type.	Surface.			Subsoil.		
			Cal- cium in HCl solu- tion.	H <sub>2</sub> O sus- pen- sion.	KCl sus- pen- sion.	Cal- cium in HCl solu- tion.	H <sub>2</sub> O sus- pen- sion.	KCl sus- pen- sion.
			Mgm.	P <sub>H</sub> .	P <sub>H</sub> .	Mgm.	P <sub>H</sub> .	P <sub>H</sub> .
13	Allen.....	Oswego silt loam....	25.3	5.43	5.16	30.6	5.33	5.02
53	Brown.....	Marshall silt loam....	30.9	5.43	5.50	29.4	5.19	4.99
51	Leavenworth...	Brown loam.....	33.2	5.66	6.04	23.0	5.43	4.99
57	Barton.....	Greensburg sandy loam.	26.3	5.93	6.07	112.0	8.00	8.06
47	Cherokee.....	Oswego clay.....	39.8	5.97	6.17	154.2	7.08	6.98
21	Harper.....	Brown loam.....	14.2	6.07	6.10	16.8	6.78	6.51
39	Jewell.....	Lincoln clay.....	42.2	6.27	6.44	54.8	6.71	6.68
41	do.....	Colby silt loam.....	27.2	6.41	6.34	78.0	7.66	7.66
19	Brown.....	Osage silt loam.....	59.3	6.41	6.54	105.0	7.39	7.76
43	Greenwood.....	Crawford silt loam....	31.8	6.48	6.64	78.0	6.85	6.85
35	Finney.....	Richland silt loam....	34.1	6.81	6.98	138.0	7.76	7.90
29	Allen.....	Oswego silt loam.....	68.2	6.98	7.08	209.0	7.71	7.66
45	Greenwood.....	Crawford clay.....	324.0	7.49	7.76	431.0	7.69	7.69
27	Jewell.....	Lincoln silt loam.....	192.0	7.49	7.86	136.0	7.56	7.73
55	Gove.....	Colby silt loam.....	78.4	7.49	7.96	284.0	7.90	8.23

The P<sub>H</sub> values on the soil suspensions in water and in the KCl solution do not differ widely except as will be noted. Hoagland and Sharp (23) found that the diffusion of KCl into the electrode vessel had a tendency to increase the H-ion concentration, the amount of increase, however, was small. It should be remembered that in soils P<sub>H</sub> numbers have no significance beyond the first decimal place. Considering the different P<sub>H</sub> values obtained, the general rule seems to be that the presence of KCl increases the concentration of the H ion or the OH ion when either is in marked excess. That is, in very acid soils the presence of KCl will increase the hydrogen-ion concentration, while in alkaline soil it will increase the hydroxyl-ion concentration. If the P<sub>H</sub> value obtained is between 6 and 7 the influence of KCl is small.

As a rule, the calcium content is higher in the subsoil than in the surface soil, and a higher calcium content is accompanied by a lower hydrogen-ion concentration. There were five soils which were exceptions to this, namely:

- No. 13, Oswego silt loam.
- No. 17, Marshall silt loam.
- No. 33, Summit silt loam.
- No. 51, Brown loam.
- No. 53, Marshall silt loam.

In these the differences in calcium content of soil and subsoil were small. As a rule, the calcium content exerted a greater influence on the reaction than did the difference between soil and subsoil. When the calcium content was high the P<sub>H</sub> values ranged between 7.5 and 8.0, which is also near the values obtained when adsorption of calcium from a(OH)<sub>2</sub> was complete.

EXPERIMENT 22.— $P_H$  OBTAINED BY ADDING VARYING AMOUNTS OF CALCIUM HYDROXIDE TO DIFFERENT SOILS

By adding  $\text{Ca}(\text{OH})_2$  to a soil in such a way that several definite but varying amounts are used, and then determining the  $P_H$  values of the different portions, it should be possible to determine the equivalent  $\text{CaCO}_3$  needed in the form of  $\text{Ca}(\text{OH})_2$  to give any desired  $P_H$  value. A number of the soils used in Experiment 21, the initial  $P_H$  number of which was less than 7, were selected for this experiment. Varying amounts of the  $\text{Ca}(\text{OH})_2$  solution and enough KCl to make the concentration 0.5N were added to three portions of soil. The amounts of  $\text{Ca}(\text{OH})_2$  to be added to the different soil portions were judged partly from the initial  $P_H$  value obtained on the soil suspension in KCl solution and partly by the general character of the soil. The solution was left in contact for the usual 24 hours. The results are given in Table XXII. The figures are grouped according to the decreasing value of the hydrogen ion concentration.

TABLE XXII.—Changes in  $P_H$  values produced by adding  $\text{Ca}(\text{OH})_2$  to different soils

Soil No.	County.	Soil type.	Calcium added, mgm.			
			0	8	16	24
			$P_H$	$P_H$	$P_H$	$P_H$
31	Allen	Oswego fine sandy loam	4.82	6.14	7.35	8.0
27	do.	Osage clay	4.82	5.87	6.95	7.9
49	Montgomery	Crawford clay	4.82	6.31	7.39	7.9
11	Allen	Summit silt loam	5.06	6.34	7.32	
23	do.	Neosho silt loam	5.06	6.61	7.52	8.6
25	do.	Osage loam	5.06	6.75	7.66	8.7
13	do.	Oswego silt loam	5.16	6.64	7.49	7.9
15	Riley	do.	5.33	6.64		7.7
17	Brown	Marshall silt loam	5.40	6.20	7.49	7.8
33	Allen	Summit silt loam	5.46	6.37	7.73	8.4
			Calcium added, mgm.			
			0	4.8	9.6	14.4
53	Brown	Marshall silt loam	5.50	6.20	6.95	7.1
51	Leavenworth	Brown loam	6.04	6.61	7.08	7.9
21	Harper	do.	6.10	7.25	7.86	8.5
			Calcium added, mgm.			
			0	2.4	4.8	7.2
57	Barton	Greensburg sandy loam	6.07	6.58	7.12	7.4
41	Jewell	Colby silt loam	6.34	6.75	7.20	7.4
39	do.	Lincoln clay	6.44	6.75	7.12	7.3
43	Greenwood	Crawford silt loam	6.44	6.95	7.08	7.5

There is in general a relationship between the initial hydrogen-ion concentration and the  $P_H$  values produced by the addition of a certain amount of  $\text{Ca}(\text{OH})_2$ . If the initial hydrogen-ion concentration is high a given amount of  $\text{Ca}(\text{OH})_2$  will produce a smaller change than if the

initial concentration is low. This is due to the neutralizing effect of the acid-producing substance. Soil texture also has an influence on the result, shown by the fact that a certain amount of  $\text{Ca}(\text{OH})_2$  will not produce as great a change in the  $\text{P}_\text{H}$  values in clay and silt soils as in sandy soils. Most soils in which the initial hydrogen-ion concentration corresponds to a  $\text{P}_\text{H}$  value of 5.5 or less required about 5 tons equivalent of  $\text{CaCO}_3$  per acre to approximate the hydroxyl-ion concentration usually found in soils of high calcium content.

EXPERIMENT 23.—TOTAL CALCIUM OF SOILS AND CALCIUM SOLUBLE IN 0.5N HYDROCHLORIC ACID AND 0.5N POTASSIUM CHLORIDE SOLUTIONS

The soils used in Experiment 18 had been previously analyzed for total calcium in connection with the work of the State soil survey. The calcium soluble in 0.5N HCl and in 0.5N KCl solution was determined by digesting at room temperature for 24 hours. The data obtained are presented in Table XXIII.

TABLE XXIII.—Total calcium and calcium soluble in 0.5N HCl and in 0.5N KCl

Soil No.	County.	Soil type.	Surface soil.			Subsoil.		
			Total.	0.5N HCl	0.5N KCl	Total.	0.5N HCl	0.5N KCl
31	Allen.....	Oswego fine sandy loam.	Mgm. 25	Mgm. 15	Mgm. 15	Mgm. 27	Mgm. 21	Mgm. 23
27	do.....	Osage clay.....	43	35	36	56	50	51
23	do.....	Neosho silt loam.....	39	17	16	36	36	39
25	do.....	Osage loam.....	50	26	25	41	28	28
40	Montgomery.....	Crawford loam.....	39	18	21	38	25	31
11	Allen.....	Summit silt loam.....	37	35	33	195	195	56
17	Brown.....	Marshall silt loam.....	45	31	26	57	37	38
33	Allen.....	Summit silt loam.....	37	18	16	31	17	19
15	Riley.....	Oswego silt loam.....	64	33	31	96	74	51
13	Allen.....	do.....	36	26	26	41	31	35
53	Brown.....	Marshall silt loam.....	62	31	27	71	29	33
51	Leavenworth.....	Brown loam.....	58	33	27	59	24	27
57	Barton.....	Greensburg sandy loam.	58	26	18	134	112	33
47	Cherokee.....	Oswego clay.....	77	35	33	181	154	145
21	Harper.....	Brown loam.....	42	14	11	47	17	16
39	Jewell.....	Lincoln clay.....	104	42	39	172	54	44
41	do.....	Colby silt loam.....	59	27	24	96	78	45
19	Brown.....	Osage silt loam.....	80	59	38	128	105	54
43	Greenwood.....	Crawford silt loam.....	49	32	29	60	57	40
35	Finney.....	Richland silt loam.....	81	34	26	421	139	33
20	Allen.....	Oswego silt loam.....	82	68	52	215	209	61
45	Greenwood.....	Crawford clay.....	320	321	47	311	434	33
37	Jewell.....	Lincoln silt loam.....	222	192	52	150	136	42
55	Gove.....	Colby silt loam.....	183	78	34	256	285	34

The total calcium obtained by the fusion method was uniformly greater than the calcium soluble in either the HCl or KCl solutions, and the differences were more marked in soils of low calcium content. This means that the lower the calcium content the lower the relative solubility. In soils of comparatively low calcium content the amount soluble in a KCl solution was nearly the same as that soluble in a HCl



solution of the same normality. When soils contained a large amount of calcium the solubility in the KCl solution was much less than in HCl, and the difference increased with increasing amounts of calcium. In several of the preceding experiments it was shown that very little or no calcium was adsorbed in the presence of KCl when the amount added in  $\text{Ca}(\text{OH})_2$  was small. This indicates that the calcium is changed to a soluble salt. Considerable amounts of calcium were adsorbed in the presence of KCl when the added amount of  $\text{Ca}(\text{OH})_2$  was large. The power of KCl to change calcium in a soil to a soluble salt is limited. Calcium in soil is usually present as a silicate or a carbonate, a salt of a weak acid and strong base. When KCl is added to soil  $\text{CaCl}_2$ , and the potassium salts of the weak acids are formed, the reaction being often described as basic exchange (47). This is a reversible reaction, governed by the law of mass action.

### GENERAL DISCUSSION

#### ORGANIC VERSUS INORGANIC ORIGIN OF ACIDITY

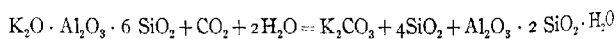
There are a number of theories relative to soil acidity, soil reaction, and lime requirements. Some of these are discussed by Fisher (13). The substance which determines whether the hydrogen ions or the hydroxyl ions shall be in excess may be of organic or inorganic origin. When organic matter decays in soil organic acids may be formed. Such a source of acidity is common in muck and peat soils (29, p. 355). In soils principally of mineral origin, organic matter apparently does not play an important rôle in the production of soil acidity (11, 25). That a considerable amount of an organic acid may be added to such mineral soils without increasing the hydrogen-ion concentration was shown in the experiment with oxalic acid. In fact, the addition of small amounts of the feebly ionized acid actually increased the hydroxyl-ion concentration, probably because of the formation of salts of a weak acid and strong base. This explains the well-known fact that instead of increasing acidity the addition of organic matter may actually decrease the same.

All of the soils used in this study were derived mostly from limestone, lime shale, and sandstone. They were therefore typical mineral soils. That organic matter does not determine the reaction of such soils is shown again by the fact that after ignition (Experiment 12) the  $P_H$  values were not materially changed. The source of the excess hydrogen-ion concentration is in the mineral portion of the soil. Harris (17, 18, 19) found many acid soils that were deficient in organic matter. Most acid soils are of mineral origin, and organic matter is only an indirect factor in the production of the acid condition.

#### ACID CONDITION PRODUCED BY WEATHERING

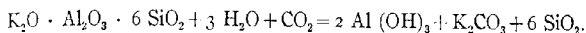
The cause of the acid condition of a mineral soil is due to chemical changes which are a part of the weathering process, or the process by which soils are formed from rocks and minerals. Acid soils are likely to be found where the annual rainfall exceeds evaporation, and alkaline soils when the opposite condition prevails. Continuous addition of  $\text{NaNO}_3$ ,  $(\text{NH}_4)_2\text{SO}_4$ , or  $\text{CaH}_2(\text{PO}_4)_2$  may also affect soil reaction (5, 10).

When silicates, such as the feldspars, undergo weathering the chemical changes which take place may be represented by the equation:



The reaction is similar when calcium or some other strong base is present in the original mineral. The base sodium has been removed from soils in humid regions to such an extent that very little is left. Under present climatic conditions calcium is the base removed in largest amount (22, p. 22-23). Since the earth's crust contains nearly the same percentage of potassium and sodium (9), and also since soils of mineral origin contain more potassium than sodium, it is indicated that potassium is less readily removed.

In the Tropics, where the conditions of weathering are more intense, the process goes further than that represented by the above equation. The equation for this more intense transformation may be written (34) —

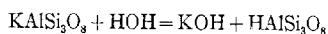


The similarities and differences of the two equations are apparent. Both show that the bases are transformed into soluble forms, and in this condition may be readily removed by leaching. However, in the formation of the aluminosilicate, kaolin, only two-thirds of the silica is set free from the original mineral. In tropical weathering, according to the above equation, all the silica is split off and the aluminum is found as the hydroxid, gibbsite, the characteristic mineral of laterite.

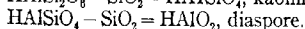
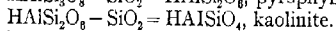
#### REMOVAL OF BASES THE FUNDAMENTAL CAUSE OF ACIDITY

The elements potassium, sodium, and calcium in those minerals which form soil are in a condition of unstable chemical equilibrium under humid climatic conditions. They form the weak link in the mineral molecule. Under the conditions of a humid climate they are removed by various agencies, and the more stable aluminosilicates found in clay are produced. This removal of bases is the fundamental cause of the acid condition of soil of mineral origin.

Cameron and Bell (6) give another picture of the chemical transformations which take place in the weathering of silicates. They write the equation as follows:



The successive removal of silica is represented as follows:



This chemical reaction explains the alkaline reaction of finely ground suspension of orthoclase in water. Under humid condition the base is removed and the acid aluminosilicate is left. This is very slightly soluble and feebly ionized.

The equations also show the splitting off of silica, and, at present, considerable amounts are being leached from the land surface (22, p. 22-23). This may be removed, at least in part, in the colloidal form (24). But the serious loss is that of calcium, which under climatic conditions is leached in large amounts from cultivated land. (30)

The carbon dioxide needed for this weathering process is derived partly from that brought to the soil in rain (9), and perhaps to a larger extent from the decay of organic matter in the soil. In this way organic matter indirectly brings about an acid condition of the soil.

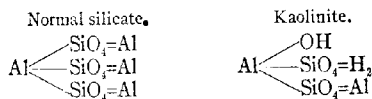
#### IMPOVERISHMENT OF CALCIUM, THE END RESULT OF WEATHERING

The net result of the weathering process is the removal of bases, mostly in carbonate form, the production of free silica, and the accumulation of the aluminosilicates. The presence of calcium in soil in the noncarbonate form indicates that all of the calcium has not been removed from these silicates. A large part of this calcium is soluble in dilute hydrochloric acid and in a 0.5N solution of KCl. In this process the potassium is taken up by the silicate and the calcium is set free in equivalent amounts (36). This process is usually called basic exchange (43, 46, 47). The ionic and adsorption theories show that calcium is made soluble because of the excess of hydrogen and chlorine ions when the adsorption of potassium takes place. The weathering process produces a soil poor in calcium. Plants need calcium for growth and development. What is often called an acid condition exists when calcium is so firmly combined with the aluminosilicates that it is unavailable for plant use. Under such a condition calcium supplied even in the form of  $\text{CaSiO}_3$  may be beneficial, not because it reduces the hydrogen ions, but because it satisfies the need of plants for calcium. When calcium in the form of  $\text{Ca}(\text{OH})_2$  is added to soils which contain these aluminosilicates the basic condition of the original mineral tends to be restored. Such recombination may be purely chemical. If this is true, there are an indefinite number of aluminosilicates in which calcium is only partly taken up. This was shown in several experiments in which the amount of calcium adsorbed was definitely related to the amount added.

#### ACID NATURE OF WEATHERED ALUMINO-SILICATES

The acid nature of weathered silicates, or the property which makes them combine with bases, can be seen from the following explanation based on Clarke's theory (8). The simplest method of representing many, perhaps all, of the orthosilicates of aluminum is as substitution derivatives of the normal salt  $\text{Al}_2(\text{SiO}_3)_3$  derived from the normal silicic acid  $\text{H}_2\text{SiO}_4$ . The existence of this silicate has not been proved, but several minerals such as nephelite,  $\text{NaAlSiO}_3$ , leucite,  $\text{KAlSiO}_3$ , and Kryptolite,  $\text{HAlSiO}_3$ , in which one or more atoms of aluminum are replaced by other metals, are known. The acid nature of the latter is suggested both by the formula and by the substitution of hydrogen for the bases potassium and sodium.

The structural formulas (8) of the normal aluminum silicate and kaolinite suggests the acid nature of the latter.



It is well known that kaolin has an acid reaction toward indicators. Fuller's earth, a substance of the same chemical nature as kaolin, gave

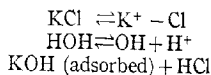
(Experiment 13) a  $P_H$  value indicating a higher hydrogen-ion concentration than that found in many acid soils. The adsorptive power for calcium was also greater. The silicates present in such materials as fuller's earth and kaolin are relatively insoluble and very feebly ionized. Rice and Osugi (39) found that the catalytic effect of the hydrogen ion from some silicates as indicated by the inversion of cane sugar was nil when KCl was absent, but considerable when this salt was present. The greater hydrogen-ion concentration produced by adding a neutral salt like KCl to an aluminosilicate is due to the adsorption of potassium (36), thus increasing the number of hydrogen ions. When a soil is suspended in water and agitated, some bases readily go into solution, as is well known by the analysis of the water extracts. Some of the hydrogen ions in a water suspension can be accounted for by the re-adsorption and consequent rearrangement of bases.

#### ADSORPTION VERSUS CHEMICAL COMBINATION

Whether the changes which occur when a hydroxide such as  $\text{Ca}(\text{OH})_2$  is added to soil shall be considered purely a chemical reaction or more in the nature of an adsorption phenomenon has been the subject of considerable study (3, 17, 18, 19, 45). Recent ideas (16, 27) concerning the relationship between molecules, such as occur in the formation of crystals, and the phenomena of adsorption would point to the conclusion that there is no sharp dividing line between a purely chemical union of elements or compounds and adsorption. If it is true that chemical compounds form when  $\text{Ca}(\text{OH})_2$  is added to soil, then from the experimental data here presented there must be an indefinite number of such compounds, all with different formulas. It is simpler to assume ordinary adsorption as an explanation.

#### THE PROCESS OF ADSORPTION

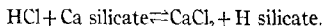
The process of adsorption was demonstrated in the experiment of Linder and Picton (28), who showed that when  $\text{As}_2\text{S}_3$  is precipitated from colloidal solution by  $\text{BaCl}_2$  a certain amount of the barium is carried down and a corresponding amount of HCl produced. Parker (36) found that when an acid soil is shaken with a solution of KCl the potassium is displaced by aluminum and other bases in nearly equivalent amounts, the chlorine remaining unchanged. However, when NaOH was also added together with the KCl his data showed that just as much potassium was absorbed, but no calcium liberated. The following equations illustrate what takes place:



In soils of relatively low calcium content the solubility of this element (Experiment 23) in 0.5N KCl was the same as in 0.5N HCl. The above equations show that in reality HCl is the dissolving agent. If a base like NaOH is present, NaCl is formed and no calcium is dissolved.

## THE CAUSE OF THE LOW INTENSITY OF SOIL ACIDITY

If the HCl formed when potassium is adsorbed from KCl remained uncombined, then the increase in hydrogen-ion concentration would be much larger than it is normally. Calcium silicates are present, and the further reaction may be represented as follows:



The relatively small hydrogen-ion concentration is due to the hypothetical feebly ionized silicic acid or the acid salt. The larger the amount of calcium in the soil, even in the form of silicates, the less the hydrogen-ion concentration. This is also the reason why in the presence of a small intensity of acidity, a relatively large amount of base such as  $\text{Ca}(\text{OH})_2$  is necessary to shift the equilibrium from a high to a lower hydrogen-ion concentration. This fact was shown in several of the preceding experiments.

## HARMFUL EFFECTS OF ALUMINO-SILICATES

Several investigators (1, 10, 20) have shown the harmful effect upon plant growth of aluminum in some soils. The net result of the weathering process is the enrichment of aluminum in the mineral matter of the soil at the same time that there is an impoverishment of the bases. In tropical weathering this is carried to the extreme, as has already been shown. The luxuriant vegetation of the Tropics would indicate that the accumulation of aluminum is not in itself harmful. Just why aluminum compounds should be toxic under some conditions and not toxic under such extreme conditions as laterite weathering is a problem which apparently has not been investigated. The explanation probably lies in the nature of the subsoil. If the subsoil is open, transference of matter takes place more readily and a better balance is maintained. The addition of calcium compounds removes the toxic effect of aluminum (20). The cycle of aluminum in nature and its effect on the physiological activities of plants is given by Stocklasa (42).

## ADSORPTION OF CALCIUM AS A PROCESS OF REPLACEMENT

The presence of such aluminosilicates as are produced by weathering probably accounts for the adsorption of calcium from such compounds as  $\text{Ca}(\text{OH})_2$  and  $\text{CaCO}_3$ . Leaching and treatment with acids, both of which may be considered as intensified processes of weathering, increased the adsorptive power of the soil (see Experiments 11 and 14). Calcium adsorption was the same whether the original acid-treated soil was high or low in calcium (see Experiments 14 and 15). The adsorptive power is conditioned upon the aluminosilicates that are produced by those processes which make soil. Adsorption in soils is a process of replacing the lost base.

## RELATIVE ADSORPTION OF CALCIUM AND POTASSIUM

When KCl is present in large amounts the need of these aluminosilicates for a base is satisfied. When the ratio of calcium to potassium was very small no calcium adsorption took place. When the ratio of

calcium to potassium was 1 to 30 about half as much calcium was adsorbed as in the absence of KCl, and considerable was adsorbed even with a wider ratio. This indicates that the adsorptive power of these aluminosilicates for calcium is greater than for potassium.

#### CONCLUDING STATEMENT

The process of weathering removes by degrees the bases in soils, and hence aluminosilicates are present with varying amounts of bases. The definite composition of many supposed minerals is questioned (38). If definite calcium aluminates exist, an equilibrium must have been reached (38). In the absence of such an equilibrium a heterogeneous mixture is present. If the removal is gradual, and substances are present with varying amounts of bases, the recombination would also be gradual. These may be purely chemical combinations, but, if so, the quantitative relationship is as would be expected by the adsorption law. This has been shown in Experiments 5 to 18. The amount of calcium adsorbed bears a certain relation to the amount added. The total amount adsorbed increases according to the amount added. When relatively small amounts are added, all is adsorbed. When larger amounts are added the greater part is adsorbed. Adsorption is further emphasized by the fact that the amount of clay has a greater effect on the amount of calcium adsorbed than the initial hydrogen-ion concentration (Experiments 19 and 22).

Many problems have been suggested by the present investigation. There are a number of factors which affect the electrometric measurements on soils. The hydrogen electrode does not give as satisfactory results with soils as it does with many other materials. The phenomenon of poisoning the electrode that exists with other materials is worse with soil. There is great need of standardizing the electrometric method for soils. Several of the experiments should be repeated on a more extensive scale; particularly those on the effect of organic acids on soils; leaching; ignition; and the acid treatment. More knowledge is needed concerning the solubility of the acid-forming substance in soil. The adsorption of the hydroxyl ions, only incidentally touched upon, needs further investigation.

#### SUMMARY

1. Acidity or alkalinity of aqueous solutions is expressed by the symbol  $P_H$  and some number which denotes the degree of the hydrogen-ion or the hydroxyl-ion concentration. The ion in excess determines whether the solution is acid or alkaline. This general concept is applied to water solutions and water suspensions of soil. The hydrogen-ion concentration in soil was measured with the hydrogen electrode. When used with soil this method presents many difficulties; these, however, are not necessarily insurmountable.

2. Since surface plays an important part, and phenomena of heterogeneity are manifest, the term adsorption rather than absorption is used to describe the combination of soil and  $Ca(OH)_2$ . Quantitatively, the combination obeys the adsorption law.

3. Successful use of the hydrogen electrode with soils depends on effective methods and efficient apparatus. A special apparatus was devised by which it is possible to carry on six electrode measurements at the same time with the minimum attention of the operator.

4. A large part of the experimental work was done on one soil, with supplementary work on other soils and materials. Calcium in the form of  $\text{Ca}(\text{OH})_2$  was added to soil in various amounts and the  $P_H$  values and unadsorbed calcium determined. This was done both in the presence and absence of  $\text{KCl}$ .  $\text{CaCO}_3$  was also used in some experiments.

5. The general effect of  $\text{KCl}$  was to increase the hydrogen-ion concentration except in soils which have a comparatively large amount of calcium. It reduced calcium adsorption from zero to one-half, more being adsorbed with the larger amount of  $\text{Ca}(\text{OH})_2$  added.

6. The hydrogen-ion concentration was greater on the suspensions than on the extracts except where there was an excess of hydroxyl ions. Leaching a soil did not decrease the hydrogen-ion concentration nor the adsorptive power; the last of these, however, was decreased by ignition. The addition of  $\text{CaCO}_3$  and  $\text{Ca}(\text{OH})_2$  did not materially affect the  $P_H$  values unless there was a long period of contact with the  $\text{CaCO}_3$ . The amount of calcium adsorbed from  $\text{Ca}(\text{OH})_2$  was not affected by the presence of  $\text{CaCO}_3$ . The adsorptive power of soil was more closely related to the clay content than to the original hydrogen-ion concentration.

7. Fuller's earth had a higher hydrogen-ion concentration and a greater adsorptive power than soil.

8. The hydrogen-ion concentration and adsorptive power of soil when treated with hydrochloric acid and washed was the same irrespective of the original calcium content of the soil.

9. Addition of small amounts of 0.04N  $\text{HCl}$  increased the hydrogen-ion concentration proportionally to the amount added. Oxalic acid of the same concentration decreased the hydrogen-ion concentration with the smaller portions of acid, and increased it with the larger portion of acid. This increase was not as great as with equivalent amounts of  $\text{HCl}$ . The difference in the effect of the two acids is due to the formation of feebly ionized salts of a weak acid and strong base in the case of the oxalic acid.

10. The fundamental cause of the acid condition of a mineral soil is found in the chemical changes which accompany weathering. The bases are removed and acid aluminosilicates accumulate. Since the removal of bases takes place gradually, readsorption would take place in a like manner. The harmful effect of these aluminosilicates is not necessarily due to the higher hydrogen-ion concentration, but more probably to the adsorption of calcium to such an extent that not enough is available for plant use. The amount of calcium adsorbed when definite amounts of a solution of  $\text{Ca}(\text{OH})_2$  is added to soil and the  $P_H$  value produced can be measured by the methods described.

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## TIME FOR TESTING MOTHER BEETS<sup>1</sup>

By DEAN A. PACK

*Plant Breeder, Sugar-Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture, Salt Lake City, Utah*

In the investigations carried on during the past three years at Salt Lake City Station, great irregularity has been noted in the quantity of sugar lost by individual sugar beets during storage. Sugar beets stored under ordinary silo conditions for three months lose from a few tenths of 1 per cent to 8 per cent of sugar. This means that of two beets each containing 16 per cent sugar at harvest one might, after storage test 15.8 and the other 10 per cent sugar. One may also find beets (a) of 20 and (b) of 17 per cent sugar at harvest time, showing spring tests (after storage) of 12 and 16 per cent sugar, respectively. This irregularity in the percentage and quantity of sugar lost by individual beets during silo storage is also to be found in beets stored under controlled moisture and temperature conditions. Yet the State experiment stations and the sugar beet companies which are developing their own seed, following the common practice, are at the present time still testing their sugar beets in the spring after these beets have been stored over winter. In view of these facts the question of the proper time for mother-beet testing forces itself upon us for immediate consideration.

### HISTORICAL

Friedl<sup>2</sup> in 1912 tested 340 beets before and after storage. These beets lost from 1 to 10 per cent of sugar during storage. He also worked in connection with several sugar factories on the loss of sugar by commercial beets during storage. From his studies he concluded that there was heavy loss of sugar in beets during storage.

### METHODS

This paper deals only with beets which were stored as usual in an ordinary silo. The beets were harvested during October, 1922, tested, weighed, and placed in storage during November, 1922. After 98 days in storage the same beets were weighed and tested as before. A special machine made at this station which permits the same beet to be sampled several times without injury was used. All beets tested by this machine came through the storage period in perfect condition. No rot or decay was found, and every beet that had been tested in the fall was again tested in the spring. The exceptionally good condition of these beets was due to the improved methods of sampling and storing employed.

A number of beets were sampled two or three times each, and the sampling method was found satisfactory from a chemical standpoint. The samples taken from beets after storage were sufficiently separated from the cuts made before storage to insure against oxidation and other

<sup>1</sup> Accepted for publication Aug. 24, 1923.

<sup>2</sup> FRIEDL, GUSTAVE. EIN BEITRAG ZUR FRAGE DER VERÄNDERUNG DER ZUCKERRÜBE WÄHREND DER LAGERUNG. In Österr. Ungar. Ztschr. Zuckerindus. u. Landw., Jahrg. 41, p. 698-712. 1912.

tissue changes occurring during storage. The chemical analysis was made according to the method devised and described by S. F. Sherwood, chemist, Sugar-Plant Investigations, United States Department of Agriculture.<sup>3</sup>

## RESULTS

Table I gives the tag numbers of beets, the percentage of sugar at harvest (fall test), percentage of sugar after storage (spring test), and the difference in the percentage of sugar before and after storage.

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
1.....	19.0	13.2	5.8	96.....	16.4	16.0	0.4
2.....	17.4	12.6	4.8	97.....	17.4	16.2	1.2
4.....	16.0	12.6	3.4	98.....	18.4	15.2	3.2
8.....	17.6	12.8	4.8	99.....	18.4	15.0	3.4
9.....	16.4	14.2	2.2	100.....	19.0	16.0	3.0
18.....	17.4	14.2	3.2	101.....	20.0	16.4	3.6
19.....	14.6	12.4	2.2	102.....	19.4	15.4	4.0
20.....	18.6	15.0	3.6	103.....	18.4	17.8	0.6
22.....	18.2	14.6	3.6	104.....	18.4	16.4	2.0
23.....	17.6	14.2	3.4	106.....	17.2	15.4	1.8
24.....	17.8	14.0	3.8	109.....	19.0	16.2	2.8
25.....	18.0	14.6	3.4	110.....	20.4	18.0	2.4
27.....	16.8	12.4	4.4	111.....	17.6	14.4	3.2
28.....	17.0	12.8	4.2	113.....	17.6	14.4	3.2
29.....	16.8	14.0	2.8	114.....	17.6	15.2	2.4
30.....	16.8	14.0	2.8	115.....	15.6	12.6	3.0
31.....	18.0	13.6	4.4	116.....	18.2	15.6	2.6
35.....	16.2	14.6	1.6	117.....	18.2	14.6	3.6
36.....	17.4	14.0	3.4	119.....	20.6	16.2	4.4
39.....	20.0	16.6	3.4	120.....	18.2	13.6	4.6
41.....	17.8	14.4	3.4	121.....	18.8	14.8	4.0
44.....	19.2	16.2	3.0	122.....	18.6	14.4	4.2
46.....	17.6	14.6	3.0	123.....	17.0	14.2	2.8
47.....	17.6	13.6	4.0	124.....	18.0	14.4	3.6
48.....	17.2	13.2	4.0	125.....	18.8	15.8	3.0
49.....	18.0	14.2	3.8	126.....	19.6	15.6	4.0
54.....	16.8	14.0	2.8	127.....	17.6	15.0	2.6
55.....	16.2	14.6	1.6	128.....	15.6	14.4	1.2
56.....	17.6	14.4	3.2	129.....	19.0	16.0	3.0
58.....	17.4	13.0	4.4	130.....	18.4	16.6	1.8
70.....	17.6	15.2	2.4	131.....	17.8	14.0	3.8
74.....	19.6	17.0	2.6	132.....	18.4	15.6	2.8
78.....	17.4	14.0	3.4	133.....	19.2	15.0	4.2
79.....	21.0	15.8	5.2	134.....	20.0	14.2	5.8
81.....	19.4	14.8	4.6	137.....	16.2	12.8	3.4
84.....	15.4	13.8	1.6	138.....	17.4	13.0	4.4
86.....	18.2	14.4	3.8	139.....	18.8	16.2	2.6
87.....	15.6	13.2	2.4	140.....	20.6	16.4	4.2
88.....	17.4	15.6	1.8	141.....	15.4	12.8	2.6
89.....	17.8	14.4	3.4	142.....	17.2	15.0	2.2
90.....	17.2	14.6	2.6	143.....	18.4	16.8	1.6
91.....	16.6	13.6	3.0	144.....	14.4	10.6	3.8
92.....	16.0	14.0	2.0	145.....	19.2	16.0	3.2
93.....	18.4	14.0	4.4	146.....	17.0	13.6	3.4
94.....	19.2	16.4	2.8	147.....	17.8	15.0	2.8
95.....	16.6	12.8	3.8	148.....	19.2	16.4	2.8

<sup>3</sup>SHERWOOD, S. F. SUCROSE IN SEED BEETS. *In* Sugar, v. 23, p. 299-300, 1921.

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
0.	18.8	16.2	2.6	227.	19.6	15.6	4.0
1.	18.4	15.0	3.4	228.	17.4	14.8	2.6
2.	18.0	15.6	2.4	229.	20.4	15.6	4.8
3.	20.0	15.4	4.6	230.	18.4	15.2	3.2
4.	18.4	15.2	3.2	231.	19.4	15.6	3.8
5.	20.6	16.0	4.6	232.	20.2	16.0	4.2
6.	20.4	17.2	3.2	233.	20.8	17.6	3.2
7.	20.2	15.6	4.6	234.	20.4	17.8	2.6
8.	20.4	15.0	5.4	235.	20.6	16.6	4.0
9.	19.0	15.6	3.4	236.	19.4	15.6	3.8
10.	19.4	15.6	3.8	237.	18.0	15.0	3.0
11.	19.4	15.0	4.4	238.	19.8	16.8	3.0
12.	17.8	15.0	2.8	239.	16.8	14.8	2.0
13.	18.0	16.6	1.4	240.	18.8	15.4	3.4
14.	18.0	14.6	3.4	241.	21.4	18.0	3.4
15.	17.4	14.6	2.8	242.	18.6	16.2	2.4
16.	17.2	14.0	3.2	243.	20.0	17.4	2.6
17.	18.2	16.0	2.2	244.	19.2	16.6	2.6
18.	18.4	17.4	1.0	245.	18.2	15.4	2.8
19.	19.6	16.8	2.8	246.	20.8	17.0	3.8
20.	17.4	15.0	2.4	247.	20.8	16.6	4.2
21.	20.0	16.4	3.6	248.	19.0	15.2	3.8
22.	20.4	17.2	3.2	249.	20.0	17.4	2.6
23.	17.6	17.0	.6	250.	18.8	16.0	2.8
24.	21.2	18.8	2.4	251.	19.4	16.0	3.4
25.	19.8	16.2	3.6	252.	19.6	15.6	4.0
26.	19.0	16.0	3.0	253.	19.2	15.0	4.2
27.	20.4	15.6	4.8	254.	18.6	16.0	2.6
28.	20.0	17.8	2.2	255.	18.6	16.0	2.6
29.	20.0	12.2	7.8	256.	19.2	16.0	3.2
30.	21.0	16.8	4.2	257.	18.6	14.4	4.2
31.	19.2	16.0	3.2	258.	18.4	15.4	3.0
32.	20.0	18.0	2.0	259.	19.4	16.4	3.0
33.	20.6	15.4	5.2	260.	17.6	17.0	.6
34.	18.4	16.0	2.4	261.	18.4	14.8	3.6
35.	21.0	17.4	3.6	262.	19.8	16.4	3.4
36.	17.6	14.2	3.4	263.	19.4	15.6	3.8
37.	19.6	17.4	2.2	264.	18.6	14.4	4.2
38.	19.0	15.2	3.8	265.	18.8	16.6	2.2
39.	17.0	14.6	2.4	266.	19.0	16.6	2.4
40.	18.0	13.6	4.4	267.	19.6	16.8	2.8
41.	20.8	15.8	5.0	268.	18.6	16.0	2.6
42.	19.2	15.6	3.6	269.	18.6	15.6	3.0
43.	20.6	17.6	3.0	270.	18.4	15.6	2.8
44.	16.6	14.6	2.0	271.	19.2	14.6	4.6
45.	20.0	16.0	4.0	272.	19.6	16.4	3.2
46.	17.8	14.0	3.8	273.	18.4	14.4	4.0
47.	18.8	15.8	3.0	274.	17.4	15.0	2.4
48.	17.2	14.2	3.0	275.	18.8	15.8	3.0
49.	17.6	13.6	4.0	276.	16.8	12.8	4.0
50.	21.0	16.0	5.0	278.	19.4	15.6	3.8
51.	19.2	15.4	3.8	279.	18.2	15.4	2.8
52.	18.0	14.8	3.2	280.	18.8	16.0	2.8
53.	17.4	13.2	4.2	281.	17.6	14.0	3.6
54.	18.4	11.6	6.8	283.	16.6	13.4	3.2
55.	18.4	14.8	3.6	286.	18.8	14.8	4.0
56.	18.0	13.4	4.6	287.	15.8	14.0	1.8
57.	15.4	13.8	1.6	288.	20.0	15.6	4.4
58.	18.8	12.0	6.8	289.	18.8	16.4	2.4
59.				290.	17.4	14.4	3.0

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
291	19.4	15.2	4.2	391	21.6	15.6	6.0
292	18.0	13.6	4.4	393	18.8	15.4	3.4
293	19.4	10.6	2.8	394	18.6	15.0	3.6
294	18.4	14.8	3.6	395	17.0	12.8	4.2
295	20.2	17.0	3.2	396	19.8	17.0	2.8
296	21.8	18.8	3.0	398	20.0	17.2	2.8
297	19.0	15.4	3.6	400	20.0	15.6	4.4
298	18.8	10.2	2.6	401	18.6	15.0	3.6
299	18.6	15.8	2.8	402	20.0	17.0	3.0
300	20.4	10.8	3.6	403	17.4	14.0	3.4
305	16.6	14.4	2.2	404	17.0	13.6	3.4
306	18.6	10.0	2.6	405	18.8	14.8	4.0
307	18.6	10.0	2.0	406	17.2	13.4	3.8
308	17.4	14.0	3.4	407	16.4	13.4	3.0
309	18.0	10.0	1.4	410	19.4	15.6	3.8
310	18.4	15.6	2.8	412	17.0	13.8	3.2
311	18.2	15.2	3.0	413	16.8	12.4	4.4
312	18.4	15.4	3.0	415	18.2	15.6	2.6
313	17.4	15.0	1.8	416	19.6	16.2	3.4
314	18.0	14.4	3.6	417	17.8	15.8	2.0
317	20.2	16.6	3.6	419	14.4	12.4	2.0
321	19.8	15.0	4.2	420	18.4	14.8	3.6
323	18.6	15.0	3.2	423	18.8	14.2	4.6
325	17.4	14.0	3.4	425	20.0	14.2	5.8
326	17.4	14.8	2.6	429	18.0	14.6	3.4
327	18.8	14.0	4.8	430	20.0	16.2	3.8
329	20.2	17.0	3.2	432	19.6	15.8	3.8
332	19.0	16.0	3.0	435	20.6	17.0	3.6
333	21.6	16.8	4.8	436	21.6	19.0	2.6
335	21.2	17.8	3.4	439	20.2	17.6	2.6
337	18.8	13.6	5.2	440	21.2	16.4	4.8
340	18.8	14.6	4.2	444	17.6	13.8	3.8
341	17.2	14.0	3.2	445	22.4	16.8	5.6
343	17.0	14.8	2.2	446	19.0	15.4	3.6
346	19.4	15.0	4.4	449	20.4	17.6	2.8
349	21.4	18.0	3.4	450	20.6	16.0	4.6
352	17.6	13.8	3.8	451	21.4	18.0	3.4
354	19.8	12.4	7.4	452	19.6	17.0	2.6
356	18.0	14.8	3.2	455	21.0	15.6	5.4
357	20.6	16.4	4.2	457	17.6	14.8	2.8
358	15.2	12.4	2.8	459	20.8	16.4	4.4
365	15.6	13.6	2.0	462	20.6	16.8	3.8
366	19.2	15.6	3.6	464	20.8	17.0	3.8
368	19.8	15.8	4.0	469	20.8	15.6	5.2
369	19.8	15.2	4.6	470	20.8	15.6	5.2
370	18.0	15.8	2.2	471	18.8	16.2	2.6
371	17.8	14.4	3.4	472	22.0	16.8	5.2
373	21.0	17.4	3.6	473	20.0	13.4	6.6
375	18.4	15.8	2.6	474	21.0	18.0	3.0
376	18.4	15.0	3.4	475	21.2	16.4	4.8
379	19.2	15.2	4.0	477	21.4	17.2	4.2
380	18.2	14.8	3.4	478	20.6	14.4	6.2
381	18.8	14.8	4.0	479	21.4	17.0	4.4
382	18.0	16.0	2.0	480	19.4	16.8	2.6
383	18.8	16.2	2.6	482	22.2	16.2	6.0
385	18.0	14.0	4.0	484	21.6	18.8	2.8
386	20.2	15.2	5.0	488	20.4	16.0	4.4
387	20.6	17.0	3.6	492	17.6	12.4	5.2
388	19.8	16.6	3.2	494	18.4	15.6	2.8

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
57	20.2	15.2	5.0	585	19.8	15.4	4.4
58	20.4	15.2	5.2	588	19.2	13.8	5.4
59	20.2	16.6	3.6	589	19.6	15.6	4.0
60	19.0	16.0	3.0	590	20.6	15.8	4.8
61	18.6	15.8	2.8	591	19.4	16.4	3.0
62	20.6	16.2	4.4	592	20.0	16.6	3.4
63	20.0	17.0	3.0	594	19.4	15.8	3.6
64	18.8	14.2	4.6	595	20.6	17.4	3.2
65	20.6	15.4	5.2	596	18.6	15.2	3.4
66	19.0	16.0	3.0	598	21.0	17.0	4.0
67	19.0	16.6	2.4	602	20.0	16.2	3.8
68	21.4	17.0	4.4	603	21.0	15.4	5.6
69	20.8	15.6	5.2	604	18.8	15.6	3.0
70	18.8	15.2	3.6	605	19.6	14.8	4.8
71	20.8	16.2	4.6	606	18.6	16.0	2.6
72	21.0	16.0	5.0	607	20.0	15.6	4.4
73	20.6	15.6	5.0	608	18.6	16.2	2.4
74	21.8	18.4	3.4	609	19.2	15.8	3.4
75	20.4	15.0	5.4	610	22.4	18.2	4.2
76	21.4	16.6	4.8	611	20.6	16.0	4.6
77	20.8	17.4	3.4	613	20.6	17.4	3.2
78	19.6	14.8	4.8	614	18.8	15.4	3.4
79	20.0	16.0	4.0	615	19.2	15.4	3.8
80	20.0	16.0	4.0	616	18.8	15.4	3.4
81	16.0	15.8	.2	618	19.8	17.8	2.0
82	18.4	13.8	4.6	626	17.6	14.6	3.0
83	20.4	16.6	3.8	627	20.0	17.2	2.8
84	19.6	14.8	4.8	630	18.8	15.6	3.2
85	19.2	14.8	4.4	635	18.4	17.0	1.4
86	20.8	15.6	5.2	636	21.4	17.4	4.0
87	20.8	15.8	5.0	637	20.4	16.0	4.4
88	21.8	17.2	4.6	638	20.2	18.0	2.2
89	20.8	16.4	4.4	640	18.6	15.0	3.6
90	19.6	16.8	2.8	642	19.4	16.2	3.2
91	19.6	16.0	3.6	643	19.8	16.4	3.4
92	19.4	16.2	3.2	644	21.2	17.6	3.6
93	19.6	16.4	3.2	645	20.6	16.4	4.2
94	20.4	16.0	4.4	646	19.4	16.4	3.0
95	20.4	15.0	5.4	647	19.8	17.0	2.8
96	20.6	17.2	3.4	648	20.4	17.0	3.4
97	20.8	14.6	6.2	649	19.0	15.0	4.0
98	21.2	16.4	4.8	650	19.6	15.6	4.0
99	20.4	16.0	4.4	651	20.4	16.6	3.8
100	21.8	15.6	6.2	652	20.0	17.4	2.6
101	19.6	14.6	5.0	656	19.8	16.4	3.4
102	20.2	16.2	4.0	660	22.4	18.6	3.8
103	20.8	16.8	4.0	662	19.8	15.2	4.6
104	20.4	16.0	4.0	668	19.6	16.0	3.6
105	20.8	17.0	3.0	670	17.6	15.2	2.4
106	18.6	15.4	3.2	671	18.4	15.2	3.2
107	20.0	15.6	4.4	672	18.8	16.6	2.2
108	21.4	15.8	5.6	673	17.8	14.6	3.2
109	20.6	18.0	2.6	675	18.4	14.6	3.8
110	20.2	15.4	4.6	676	20.6	16.2	4.4
111	19.4	15.6	3.8	681	19.8	15.6	4.2
112	19.6	16.2	3.4	683	19.6	15.2	4.4
113	19.2	16.0	3.2	690	20.0	16.2	3.8
114	19.6	14.6	5.0	692	19.8	17.0	2.8
115	19.8	16.6	3.2	703	17.4	14.4	3.0



TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
707.....	20.0	18.8	1.2	774.....	19.8	16.6	3.2
709.....	19.8	14.2	5.6	775.....	20.4	17.2	3.2
712.....	19.8	17.2	2.6	776.....	20.8	15.8	5.0
715.....	18.6	15.4	3.2	777.....	20.4	18.0	2.4
716.....	21.0	17.0	4.0	778.....	20.0	15.8	4.2
717.....	18.6	15.2	3.4	779.....	19.6	15.6	4.0
718.....	18.0	15.2	2.8	780.....	19.6	17.6	2.0
719.....	20.2	15.6	4.6	781.....	18.8	15.0	3.8
720.....	19.0	14.4	4.6	782.....	19.4	14.0	5.4
721.....	18.8	15.6	3.2	783.....	19.6	15.0	4.6
722.....	19.2	14.8	4.4	784.....	19.6	14.6	5.0
723.....	19.8	14.8	5.0	785.....	20.6	15.6	5.0
724.....	18.4	14.6	3.8	786.....	17.6	14.2	3.4
725.....	18.4	13.2	5.2	787.....	18.0	16.6	1.4
726.....	19.2	16.2	3.0	788.....	19.0	15.6	3.4
727.....	19.8	14.0	5.8	789.....	21.2	17.2	4.0
728.....	17.0	14.0	3.0	790.....	17.8	14.0	3.8
730.....	19.4	15.4	4.0	791.....	18.2	14.2	4.0
731.....	17.4	14.0	3.4	792.....	16.8	12.2	4.6
732.....	17.2	13.6	3.6	793.....	18.4	16.0	2.4
733.....	18.8	15.0	3.8	794.....	19.4	16.6	2.8
734.....	17.6	15.6	2.0	795.....	17.8	14.6	3.2
735.....	16.6	14.8	1.8	796.....	18.8	16.8	2.0
736.....	18.6	16.2	2.4	797.....	18.0	15.9	2.1
738.....	17.2	14.6	2.6	798.....	17.4	14.2	3.2
739.....	18.8	14.8	4.0	799.....	20.4	14.8	5.6
740.....	19.4	15.6	3.8	800.....	21.6	17.0	4.6
741.....	21.6	17.2	4.4	801.....	22.4	16.8	5.6
742.....	20.4	16.2	4.2	802.....	19.2	16.8	2.4
743.....	18.8	13.6	5.2	803.....	19.6	16.2	3.4
744.....	20.4	16.2	4.2	804.....	19.4	14.8	4.6
746.....	20.0	15.6	4.4	805.....	19.6	17.0	2.6
747.....	20.0	18.6	1.4	806.....	19.4	16.6	2.8
748.....	21.2	17.2	4.0	807.....	18.8	14.6	4.2
749.....	18.0	13.2	4.8	808.....	20.0	16.8	3.2
750.....	20.6	15.8	4.8	809.....	18.6	15.0	3.6
751.....	18.4	14.8	3.6	810.....	19.0	14.6	4.4
752.....	19.6	14.8	4.8	811.....	19.2	13.0	6.2
753.....	22.4	16.2	6.2	812.....	20.6	14.6	6.0
754.....	19.8	15.6	4.2	813.....	19.8	15.8	4.0
755.....	19.8	16.6	3.2	814.....	19.4	14.2	5.2
756.....	19.4	16.4	3.0	815.....	19.4	15.2	4.2
757.....	20.0	17.0	3.0	816.....	17.4	15.4	2.0
758.....	19.0	14.6	4.4	817.....	20.6	16.8	3.8
759.....	20.8	15.4	5.4	818.....	20.6	15.2	5.4
760.....	18.8	15.6	3.2	819.....	18.6	13.8	4.8
761.....	17.8	14.8	3.0	820.....	19.4	14.6	4.8
762.....	19.6	15.6	4.0	821.....	20.4	15.6	4.8
763.....	19.6	16.2	3.4	822.....	19.6	14.4	5.2
764.....	20.2	17.2	3.0	823.....	19.8	17.2	2.6
765.....	20.4	17.2	3.2	824.....	20.6	17.4	3.2
766.....	19.0	16.4	2.6	826.....	21.0	17.6	3.4
767.....	21.2	17.6	3.6	827.....	20.8	17.8	3.0
768.....	20.4	16.4	4.0	828.....	18.0	13.8	4.2
769.....	20.8	17.8	3.0	829.....	21.0	17.6	3.4
770.....	20.8	16.8	4.0	830.....	19.6	16.0	3.6
771.....	19.6	16.4	3.2	831.....	19.6	15.2	4.4
772.....	21.4	16.2	5.2	832.....	18.2	15.4	2.8
773.....	21.6	17.6	4.0	833.....	19.4	16.4	3.0

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
64.....	19.6	17.8	2.8	893.....	20.6	17.4	3.2
65.....	20.4	17.0	3.4	894.....	20.0	16.2	3.8
66.....	18.8	14.8	4.0	895.....	22.2	17.6	4.6
67.....	20.4	16.2	4.2	896.....	20.6	16.0	4.6
68.....	19.0	16.2	2.8	897.....	20.4	17.0	3.4
69.....	19.6	14.0	5.6	898.....	21.0	17.0	4.0
70.....	18.2	14.4	3.8	899.....	20.8	17.6	3.2
71.....	20.0	15.4	4.6	900.....	20.0	17.2	2.8
72.....	18.6	15.0	3.6	901.....	20.2	15.8	4.4
73.....	17.4	14.0	3.4	902.....	20.4	15.8	4.6
74.....	18.8	15.8	3.0	903.....	21.0	17.6	3.4
75.....	20.4	16.8	3.6	904.....	19.8	16.8	3.0
76.....	21.2	17.8	3.4	905.....	20.0	16.8	3.2
77.....	20.0	17.0	3.0	906.....	15.8	14.6	1.2
78.....	18.4	14.0	4.4	907.....	19.0	16.4	2.6
79.....	19.0	16.0	3.0	908.....	18.8	16.6	2.2
80.....	20.4	17.2	3.2	909.....	20.0	17.2	2.8
81.....	19.0	15.6	3.4	910.....	21.0	16.4	4.6
82.....	21.2	17.0	4.2	911.....	20.0	16.8	3.2
83.....	20.0	17.6	2.4	912.....	21.0	16.6	4.4
84.....	20.4	18.0	2.4	913.....	19.4	16.4	3.0
85.....	21.6	17.6	4.0	914.....	20.6	15.4	5.2
86.....	20.2	16.0	4.2	915.....	22.2	17.2	5.0
87.....	20.2	17.6	2.6	916.....	19.8	16.0	3.8
88.....	19.8	16.0	3.8	917.....	17.8	15.8	2.0
89.....	21.6	16.6	5.0	918.....	18.0	15.2	2.8
90.....	18.0	17.2	.8	919.....	20.8	17.4	3.4
91.....	19.4	15.0	5.4	920.....	21.0	18.2	2.8
92.....	20.8	16.8	4.0	921.....	20.0	16.2	3.8
93.....	19.8	17.6	2.2	922.....	20.0	16.8	3.2
94.....	21.0	16.4	4.6	923.....	20.4	17.2	3.2
95.....	20.0	15.4	4.6	924.....	17.2	14.4	2.8
96.....	16.6	14.2	2.4	925.....	19.6	16.0	3.6
97.....	18.8	16.2	2.6	926.....	18.4	15.4	3.0
98.....	20.8	17.0	3.8	927.....	18.6	15.6	3.0
99.....	21.6	15.6	6.0	928.....	17.0	14.0	3.0
100.....	20.0	15.4	4.6	929.....	16.0	15.2	0.8
101.....	20.0	15.8	4.2	930.....	19.0	16.0	3.0
102.....	19.0	16.6	2.4	931.....	16.8	13.6	3.2
103.....	18.6	14.6	4.0	932.....	18.2	15.0	3.2
104.....	19.8	15.8	4.0	933.....	18.2	14.8	3.4
105.....	19.6	14.0	5.6	934.....	19.2	15.2	4.0
106.....	20.0	15.8	4.2	935.....	19.2	15.2	4.0
107.....	17.8	13.6	4.2	936.....	19.2	15.2	4.0
108.....	17.6	13.8	3.8	937.....	18.4	15.8	2.6
109.....	18.4	14.4	4.0	938.....	19.8	16.2	3.6
110.....	18.4	14.6	3.8	939.....	21.4	17.4	4.0
111.....	20.0	16.0	4.0	940.....	19.6	16.0	3.6
112.....	22.6	16.0	6.6	941.....	19.4	16.0	3.4
113.....	19.0	13.2	5.8	942.....	20.0	16.0	4.0
114.....	20.0	16.4	3.6	943.....	20.8	17.0	3.8
115.....	20.4	15.6	4.8	944.....	21.0	16.2	4.8
116.....	19.8	14.4	5.4	945.....	20.6	16.4	4.2
117.....	20.2	16.2	4.0	946.....	18.2	15.2	3.0
118.....	21.2	16.4	4.8	947.....	18.8	15.6	3.2
119.....	20.6	17.2	3.4	948.....	18.6	14.2	4.4
120.....	21.4	17.6	3.8	949.....	19.6	15.4	4.2
121.....	20.4	15.4	5.0	950.....	21.2	16.0	5.2
122.....	20.0	16.4	3.6	951.....	20.6	15.6	5.0
				952.....	20.0	15.6	4.4
				953.....			
				954.....			

TABLE I.—Percentage of sugar shown by fall and spring tests and the difference between the two—Continued

Tag No.	Fall test.	Spring test.	Difference.	Tag No.	Fall test.	Spring test.	Difference.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
955.....	19.8	15.6	4.2	1014.....	19.2	15.4	3.8
956.....	19.2	15.0	4.2	1015.....	20.4	15.2	5.2
957.....	20.4	15.0	5.4	1016.....	18.4	15.0	3.4
958.....	20.0	17.6	2.4	1017.....	18.6	14.8	3.8
959.....	20.4	17.4	3.0	1018.....	20.0	16.6	3.4
960.....	18.4	15.8	2.6	1019.....	18.6	15.6	3.0
961.....	20.0	15.6	4.4	1020.....	18.8	14.8	4.0
962.....	20.0	15.8	4.2	1021.....	19.4	16.4	3.0
963.....	19.6	15.2	4.4	1022.....	20.0	14.8	5.2
964.....	20.0	17.0	3.0	1023.....	18.8	15.6	3.2
965.....	20.0	17.0	3.0	1024.....	20.0	17.4	2.6
966.....	19.2	15.6	3.6	1025.....	20.0	16.2	3.8
967.....	20.0	15.4	4.6	1026.....	19.0	14.8	4.2
968.....	18.6	14.6	4.0	1027.....	16.8	13.8	3.0
969.....	18.4	16.4	2.0	1028.....	20.4	16.6	3.8
970.....	18.6	15.0	3.6	1029.....	19.4	14.6	4.8
971.....	19.6	15.6	4.0	1030.....	19.0	15.0	4.0
972.....	21.2	17.8	3.4	1031.....	18.6	15.6	3.0
973.....	18.6	14.8	3.8	1032.....	20.2	16.6	3.6
974.....	17.2	14.8	2.4	1033.....	17.0	14.0	3.0
975.....	18.6	15.6	3.0	1034.....	21.0	17.4	3.6
976.....	20.4	15.0	5.4	1035.....	21.0	16.6	4.4
977.....	18.6	14.2	4.4	1036.....	19.0	16.2	2.8
978.....	17.4	13.8	3.6	1037.....	18.0	15.2	2.8
979.....	21.6	18.2	3.4	1038.....	18.0	15.4	2.6
981.....	19.2	16.0	3.2	1156.....	17.0	15.2	1.8
982.....	18.6	14.2	4.4	1171.....	16.8	15.6	1.2
983.....	19.6	15.6	4.0	1184.....	16.0	13.8	2.2
984.....	19.6	15.2	4.4	1193.....	16.6	15.0	1.6
985.....	19.8	15.4	4.4	1206.....	15.0	13.4	1.6
986.....	16.4	13.6	2.8	1207.....	17.6	15.4	2.2
987.....	18.8	16.4	2.4	1211.....	14.8	13.6	1.2
988.....	16.6	14.4	2.2	1212.....	15.6	14.2	1.4
990.....	20.0	15.6	4.4	1215.....	15.6	14.4	1.2
991.....	19.2	15.4	3.8	1216.....	17.6	15.8	1.8
992.....	16.8	13.4	3.4	1224.....	13.6	11.8	1.8
993.....	19.4	15.2	4.2	1226.....	15.2	14.8	.4
994.....	20.2	16.0	4.2	1228.....	17.0	14.8	2.2
995.....	20.0	14.6	5.4	1231.....	15.8	15.2	.6
996.....	19.0	15.2	3.8	1233.....	14.4	13.2	1.2
997.....	20.4	15.8	4.6	1245.....	18.4	16.2	2.2
998.....	20.0	16.4	3.6	1254.....	15.2	14.8	.4
999.....	19.0	16.2	2.8	1255.....	17.4	16.4	1.0
1000.....	22.4	18.8	3.6	1256.....	15.6	14.2	1.4
1001.....	20.2	16.6	3.6	1257.....	16.8	15.4	1.4
1002.....	20.8	17.0	3.8	1258.....	17.0	14.8	2.2
1003.....	19.4	16.6	2.8	1259.....	17.4	15.8	1.6
1004.....	19.6	15.6	4.0	1266.....	16.2	14.0	2.2
1005.....	20.8	16.0	4.8	1272.....	16.6	14.4	2.2
1006.....	19.6	15.8	3.8	1273.....	16.8	14.6	2.2
1007.....	20.0	16.6	3.4	1282.....	16.8	15.4	1.4
1008.....	19.8	15.6	4.2	1289.....	17.2	14.2	3.0
1009.....	20.0	17.2	2.8	1302.....	17.6	15.6	2.0
1010.....	21.8	18.4	3.4	1315.....	16.4	14.6	1.8
1011.....	20.2	15.8	4.4	1318.....	18.6	15.4	3.2
1012.....	19.2	15.8	3.4	1323.....	14.6	12.6	2.0
1013.....	20.6	16.8	3.8	1328.....	15.8	15.2	.6

The results here shown indicate that the difference in the percentage of sugar before and after storage is very irregular. In looking over this table one does not seem to find any relation whatsoever between the fall test and the difference in the percentage of sugar before and after storage. It is likewise difficult to see any relation between this difference and the spring test for any one beet. One could not derive the fall test of any beet from the spring test, and as a result, the breeder is at a loss to select from his spring-test data those beets that will test high at harvest time. It would therefore be quite impossible to breed up a strain of beets which would test high at harvest by making selections from spring tests.

In order to determine what relation exists between the percentage of sugar originally contained in the beet and the percentage which it loses during storage, correlation tables were made. Table II gives the correlation as determined from Friedl's analysis.

TABLE II.—Correlation between percentage of sugar in beet and loss in percentage of sugar during storage

Percentage of sugar in beet.	Loss in percentage during storage.																											
	0-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100	1-25	25-50	50-75	75-100
0-25																												
25-50	1																											
50-75		2																										
75-100			2																									
1-25				2																								
25-50					2																							
50-75						2																						
75-100							2																					
1-25								2																				
25-50									2																			
50-75										2																		
75-100											2																	
1-25												2																
25-50													2															
50-75														2														
75-100															2													
1-25																2												
25-50																	2											
50-75																		2										
75-100																			2									

The results shown in this table indicate a correlation value of 0.272 or 0.338 between the percentage of sugar originally found in the beet and the decrease in percentage during storage.

The results from the analytical data of Table I are given in the following table:

TABLE III.—Correlation between percentage of sugar in beet and loss in percentage of sugar during storage (from columns 2 and 3 of Table I)

Percentage of sugar in beet.	Loss in percentage during storage.							
	0-5	1-5	2-5	3-5	4-5	5-5	6-5	7-5
0-5								
1-5								
2-5								
3-5								
4-5								
5-5								
6-5								
7-5								
0-5								
1-5								
2-5								
3-5								
4-5								
5-5								
6-5								
7-5								
0-5								
1-5								
2-5								
3-5								
4-5								
5-5								
6-5								
7-5								

The results here shown give a correlation coefficient of  $0.462 \pm 0.015$  between the percentage of sugar in the beet at harvest and the decrease in percentage in individual beets during storage.

These tables also indicate that the beets of high percentage at harvest tend to decrease more in percentage of sugar during storage than do the low-testing beets; as a consequence, beets of high test at harvest tend to be low in the spring, while beets of low test at harvest tend to be relatively high in the spring. The inclination on the part of the breeder is, therefore, to select the low fall-testing beets, since these show a relatively higher percentage of sugar at planting time. A breeder, for example, guided only by the spring-testing data (see Table I) would select for seed production the beets tagged 74, 103, 110, and 155 as the most desirable among the first 100 listed. In making his selections he would choose beets testing the highest according to his data—that is, beets showing 17 or more per cent of sugar. Now, on examining the fall tests one finds that there were really 11 beets containing 20 or more per cent of sugar. Their tag numbers are 39, 79, 101, 110, 119, 134, 140, 152, 153, 155, and 156. So our breeder would select two beets containing 20 per cent of sugar and would neglect nine other beets containing 20 to 21 per cent. With these two 20 per cent beets he would select two others of less than 20 per cent. Therefore, after a few years his lines should show a decrease in the average percentage of sugar.

Friedl did not give the weight of each beet along with the percentage of sugar which it contained, and, consequently, we do not know just how much of the decrease in sugar was due to the water intake of each beet during storage. He made dry weight determinations on other beets and found an increase of 6 per cent of water during storage which would correspond to about 1 per cent decrease in the percentage of sugar. Therefore, his results show that there was a too great difference between the fall and spring tests to be accounted for by decrease in the percentage of sugar (due to intake of water) and it is evident that there was also a marked loss of the actual sugar in the beet.

In the present work the order of weighing and sampling beets was arranged so that comparable weights and percentage of sugar were obtained for each beet. The order was as follows: First, sample at harvest time, weight of sampled beet, storage for 98 days, weight of sampled beet; and second, sample (98 days after first sample was taken).

Table IV gives for each beet these weights before and after storage, the sugar content before and after storage, and the loss of sugar in grams during storage. The same tag numbers in this table and Table I denote identical beets. The sugar content of each beet before and after storage is the product of the weight and its corresponding percentage of sugar (from Table I). For example, beet tagged 1 before storage tested 19.0, weighed 1,100 gm. and contained 209 gm. of sugar; after storage this beet weighed 1,110 gm., tested 13.2, and contained 147 gm. of sugar.

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
1.	1,100	209	1,110	147	62
1.	1,330	231	1,475	186	45
1.	1,385	221	1,520	191	30
3.	1,185	208	1,340	171	37
1.	1,420	232	1,500	213	19
8.	1,158	202	1,275	181	21
9.	1,810	264	1,960	243	21
0.	825	153	825	123	30
2.	890	162	960	140	22
3.	1,495	263	1,600	227	36
4.	1,280	229	1,420	199	30
5.	1,382	240	1,530	227	22
7.	1,625	273	1,725	214	59
8.	1,275	217	1,362	174	43
9.	1,385	233	1,500	210	23
0.	976	164	1,037	145	19
1.	1,420	256	1,525	207	49
5.	1,255	203	1,360	199	4
6.	795	137	900	126	11
9.	1,105	221	1,110	184	37
1.	825	149	905	130	19
4.	1,380	264	1,440	233	31
6.	1,100	194	1,200	175	19
7.	1,155	203	1,237	168	35
8.	1,015	174	1,075	142	32
9.	1,245	224	1,310	186	38
4.	955	160	1,040	146	14
5.	1,080	175	1,175	172	3
6.	1,344	230	1,530	220	16
8.	1,105	192	1,205	157	35
0.	719	126	825	125	1
4.	1,312	257	1,300	221	36
8.	800	130	860	120	19
9.	1,040	218	1,125	178	40
1.	1,112	216	1,061	157	59
4.	1,720	265	1,900	262	3
6.	910	166	1,000	144	22
7.	1,152	180	1,025	162	18
8.	1,090	190	1,125	175	15
9.	1,585	282	1,725	248	34
0.	890	153	930	136	17
1.	1,305	217	1,362	185	32
2.	1,460	234	1,575	220	14
3.	2,060	379	2,085	292	87
4.	775	149	800	131	18
5.	1,090	181	1,140	146	35
6.	880	144	900	144	0
7.	1,270	221	1,260	204	17
8.	1,585	292	1,680	255	37
9.	1,178	217	1,250	187	30
20.	830	158	850	136	22
21.	970	194	990	162	32
22.	745	144	760	117	27
23.	1,430	263	1,510	269	6
24.	965	177	990	162	15
26.	917	158	1,000	154	4
29.	965	183	1,040	163	15
30.	1,090	222	1,110	200	22

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
111.....	995	175	1,065	153	22
113.....	1,820	320	1,920	276	44
114.....	1,670	293	1,775	270	23
115.....	1,600	250	1,620	204	46
116.....	1,705	310	1,620	253	57
117.....	1,690	308	1,740	154	154
119.....	730	150	870	141	5
120.....	1,205	219	1,300	177	45
121.....	1,190	224	1,310	194	50
122.....	1,220	227	1,325	191	54
123.....	1,085	185	1,160	165	20
124.....	1,080	201	1,180	170	31
125.....	1,120	211	1,370	216	7
126.....	1,350	265	1,520	237	20
127.....	1,240	218	1,575	236	15
128.....	1,620	253	1,650	238	16
129.....	1,170	222	1,250	200	22
130.....	980	180	1,020	160	11
131.....	1,235	220	1,350	189	21
132.....	870	160	935	146	14
133.....	1,425	274	1,500	225	46
134.....	1,020	204	1,050	149	33
137.....	1,530	248	1,620	207	41
138.....	1,085	189	1,150	149	46
139.....	1,070	201	1,200	194	25
140.....	1,260	260	1,312	215	25
141.....	1,395	215	1,450	186	27
142.....	1,715	295	1,775	166	25
143.....	880	102	950	159	25
144.....	1,515	218	1,650	175	40
145.....	1,640	315	1,755	281	72
146.....	1,420	241	1,575	214	27
147.....	1,090	194	1,130	169	21
148.....	850	163	887	145	19
149.....	860	162	875	142	25
150.....	1,335	245	1,390	200	22
151.....	1,200	216	1,210	180	27
152.....	1,560	312	1,725	266	46
153.....	1,105	203	1,200	182	22
154.....	1,070	220	1,170	187	33
155.....	1,015	207	1,050	180	27
156.....	770	155	850	133	22
157.....	815	166	850	127	25
158.....	1,400	266	1,500	234	42
159.....	1,400	272	1,400	218	42
160.....	1,390	270	1,462	209	62
165.....	1,115	198	1,200	180	28
168.....	945	170	930	154	16
173.....	940	169	1,012	148	21
174.....	1,330	231	1,500	210	21
175.....	970	167	1,075	150	27
176.....	1,220	222	1,275	204	19
177.....	770	142	770	134	1
178.....	930	182	940	158	24
180.....	1,560	271	1,690	254	27
183.....	850	173	915	150	21
186.....	1,155	236	1,190	205	25
190.....	1,380	243	1,425	242	1

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
1.....	1,080	229	1,110	209	20
2.....	1,670	331	1,725	279	52
3.....	930	177	975	156	21
4.....	1,320	269	1,525	238	31
5.....	1,670	336	1,720	306	30
6.....	1,140	228	1,187	145	83
7.....	1,210	254	1,280	215	39
8.....	1,335	256	1,400	224	32
9.....	1,415	283	1,480	266	17
10.....	1,170	241	1,320	203	38
11.....	1,545	284	1,570	251	33
12.....	1,110	233	1,154	201	32
13.....	1,025	180	1,062	151	29
14.....	1,470	288	1,450	252	36
15.....	1,180	224	1,260	192	32
16.....	1,035	175	1,080	147	28
17.....	1,200	216	1,300	177	39
18.....	1,070	222	1,110	175	47
19.....	1,380	264	1,515	236	28
20.....	1,110	229	1,125	198	31
21.....	1,100	183	1,125	164	19
22.....	980	196	1,040	166	30
23.....	1,040	185	1,075	150	35
24.....	1,325	249	1,375	217	32
25.....	1,580	271	1,700	241	30
26.....	1,255	221	1,350	184	37
27.....	1,270	267	1,360	218	49
28.....	1,220	234	1,300	200	34
29.....	1,450	261	1,500	222	39
30.....	640	111	650	86	25
31.....	795	132	890	103	28
32.....	810	149	850	126	23
33.....	595	107	637	85	22
34.....	760	117	800	1,010	7
35.....	870	164	950	114	49
36.....	800	157	890	139	18
37.....	945	164	950	141	23
38.....	1,040	212	1,150	179	33
39.....	1,010	180	1,065	162	28
40.....	780	152	820	128	24
41.....	950	192	987	158	34
42.....	875	182	900	158	24
43.....	900	184	900	160	24
44.....	960	198	1,020	169	29
45.....	730	142	800	125	17
46.....	1,330	239	1,360	204	35
47.....	850	168	890	149	19
48.....	1,230	207	1,320	195	12
49.....	850	160	930	143	17
50.....	1,025	219	1,110	200	19
51.....	860	159	870	141	18
52.....	870	174	900	156	18
53.....	900	173	925	153	20
54.....	1,090	198	1,162	179	19
55.....	1,110	231	1,200	204	27
56.....	930	193	1,025	170	23
57.....	990	188	1,035	157	31
58.....	1,015	203	1,000	174	29



TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—*Cont.*

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
250.....	1,460	274	1,470	235	31
252.....	1,060	206	1,150	184	44
253.....	900	176	962	150	44
254.....	915	176	1,050	157	44
255.....	980	182	1,005	161	44
256.....	725	139	825	132	44
257.....	1,330	247	1,450	209	44
258.....	905	166	950	146	44
259.....	810	157	875	143	44
260.....	1,150	202	1,230	209	44
261.....	1,100	202	1,160	172	44
262.....	1,135	224	1,210	198	44
263.....	940	182	1,040	162	44
264.....	895	166	912	131	44
265.....	1,830	344	1,850	307	44
266.....	1,560	296	1,575	261	44
267.....	1,270	249	1,375	231	44
268.....	2,000	372	2,050	328	44
269.....	1,090	203	1,150	179	44
270.....	1,375	253	1,375	214	44
271.....	855	164	830	121	44
272.....	1,305	256	1,425	233	44
273.....	1,380	254	1,415	204	44
274.....	2,120	368	2,200	330	44
275.....	1,530	288	1,650	261	44
276.....	950	160	1,010	120	44
278.....	825	160	870	136	44
279.....	1,005	183	1,080	166	44
280.....	1,335	251	1,400	224	44
281.....	825	145	890	125	44
283.....	1,350	224	1,355	182	44
286.....	1,520	286	1,700	252	44
287.....	2,160	341	2,300	322	44
288.....	1,295	259	1,420	222	44
289.....	1,450	273	1,525	250	44
290.....	1,630	284	1,700	244	44
291.....	910	176	980	149	44
292.....	1,360	245	1,437	195	44
293.....	1,815	352	1,900	315	44
294.....	1,080	199	1,115	165	44
295.....	1,290	261	1,370	233	44
296.....	985	215	1,010	190	44
297.....	1,685	320	1,825	281	44
298.....	1,280	241	1,375	223	44
299.....	1,490	277	1,580	250	44
300.....	1,220	248	1,275	214	44
305.....	1,800	299	1,960	282	44
306.....	1,415	263	1,500	240	44
307.....	1,735	323	1,760	292	44
308.....	1,525	265	1,650	231	44
309.....	1,735	312	1,850	307	44
310.....	1,010	186	1,000	156	44
311.....	930	169	1,040	158	44
312.....	1,585	292	1,700	262	44
313.....	885	154	870	136	44
314.....	1,735	312	1,875	270	44
317.....	1,405	284	1,500	249	44
321.....	1,340	265	1,470	229	44

TABLE IV.—Loss of sugar in grams by individual beets during 93 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
123	980	182	1,060	159	23
125	1,020	177	1,087	151	26
126	1,240	216	1,290	191	25
127	1,280	241	1,362	190	51
130	1,060	214	1,100	187	27
132	1,050	199	1,237	198	7
133	1,180	250	1,100	196	54
137	980	184	1,110	151	33
140	770	145	865	126	19
141	1,105	190	1,225	171	10
143	930	158	1,015	150	8
145	870	169	960	144	25
149	815	174	850	153	21
152	1,175	207	1,150	159	48
154	1,190	236	1,225	152	84
156	1,135	204	1,225	181	23
157	920	189	1,000	164	25
159	1,795	259	1,800	223	36
165	1,110	173	1,170	159	14
166	1,200	230	1,320	206	24
168	900	178	920	150	28
169	750	148	850	120	10
170	1,280	230	1,350	213	17
171	1,270	226	1,375	198	28
173	1,080	227	1,175	204	23
175	975	179	1,000	158	21
176	1,275	235	1,325	199	36
179	1,155	222	1,275	194	28
180	980	178	1,060	157	21
181	820	154	875	120	25
182	975	175	1,025	164	11
183	885	166	950	154	12
185	1,075	193	1,160	162	31
186	705	142	800	121	21
187	835	172	850	144	28
188	1,340	265	1,400	232	33
191	790	171	880	137	34
193	1,015	191	1,110	171	20
194	915	170	1,050	157	13
195	1,090	185	1,150	147	38
199	1,010	200	1,037	176	24
203	805	161	850	146	15
205	900	180	940	147	33
207	915	170	965	145	25
209	1,165	233	1,280	212	21
211	950	165	1,030	144	21
214	810	138	860	117	21
216	970	182	1,050	155	27
217	845	145	900	121	24
219	945	150	980	131	19
220	965	187	1,050	164	13
222	640	109	675	93	16
223	720	121	750	93	28
226	1,110	202	1,175	183	19
227	885	174	950	154	20
229	1,055	188	1,050	166	22
230	990	143	1,040	120	14
231	1,340	247	1,425	211	36

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
423.....	800	150	910	129	1
425.....	795	159	900	128	1
429.....	910	164	1,000	146	1
430.....	900	180	990	160	26
432.....	960	188	1,050	166	21
435.....	990	204	1,060	180	21
436.....	1,230	266	1,290	245	21
439.....	1,285	260	1,030	181	77
440.....	925	106	1,040	171	21
444.....	940	165	1,000	138	21
445.....	820	184	890	150	21
446.....	1,352	257	1,400	216	21
449.....	860	175	875	154	21
450.....	990	204	1,050	168	26
451.....	1,190	254	1,225	220	21
452.....	1,858	364	1,900	323	21
455.....	1,052	221	1,175	183	21
457.....	1,098	193	1,175	174	21
459.....	1,074	223	1,150	189	21
462.....	1,390	286	1,460	245	47
464.....	950	198	1,050	178	21
469.....	750	156	800	125	21
470.....	1,000	208	1,125	175	21
471.....	1,360	261	1,425	230	21
472.....	1,050	231	1,050	168	21
473.....	1,370	274	1,462	196	21
474.....	1,180	248	1,260	227	21
475.....	1,090	231	1,140	187	21
477.....	675	144	700	120	21
478.....	1,090	224	1,250	180	21
479.....	960	205	1,025	174	21
480.....	1,120	217	1,200	202	21
482.....	680	151	712	115	21
484.....	1,010	218	1,050	197	21
488.....	1,117	240	1,100	176	61
492.....	1,130	199	1,270	157	21
494.....	2,050	377	2,000	313	61
497.....	820	166	900	137	21
498.....	1,005	205	1,125	171	21
501.....	1,076	220	1,100	183	21
503.....	1,240	236	1,300	208	21
505.....	1,260	234	1,350	213	21
506.....	780	161	870	141	21
507.....	830	166	850	144	21
508.....	850	160	925	131	21
509.....	835	172	925	142	21
510.....	1,160	227	1,150	184	41
511.....	1,330	253	1,350	224	21
512.....	650	139	668	112	21
514.....	780	162	850	133	21
515.....	1,250	235	1,325	201	21
516.....	1,460	303	1,490	241	61
517.....	690	144	790	126	21
519.....	900	185	987	154	21
520.....	745	162	790	145	21
521.....	791	161	880	132	21
522.....	815	187	900	149	21
523.....	1,220	253	1,275	222	21

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
15.....	850	167	910	135	32
17.....	830	166	890	142	24
18.....	1,340	268	1,375	220	48
19.....	1,055	169	1,075	170	1
20.....	910	167	1,000	138	29
21.....	1,020	208	1,075	178	30
22.....	995	195	1,075	159	36
23.....	870	167	925	137	30
24.....	1,020	212	1,050	164	48
25.....	1,000	208	1,070	169	39
26.....	620	135	700	120	15
27.....	780	162	825	135	27
28.....	1,110	217	1,125	189	28
29.....	865	168	900	146	22
30.....	660	129	725	119	10
31.....	660	129	725	126	3
32.....	860	175	900	144	31
33.....	805	164	900	135	29
34.....	1,280	264	1,337	230	34
35.....	1,020	212	1,187	173	39
36.....	870	184	1,012	166	18
37.....	1,110	226	1,150	184	42
38.....	820	179	940	147	32
39.....	1,105	217	1,210	177	40
40.....	990	200	1,100	178	22
41.....	875	182	940	158	24
42.....	900	184	937	150	34
43.....	745	155	850	144	11
44.....	1,120	208	1,275	196	12
45.....	750	150	825	129	21
46.....	950	203	1,200	190	13
47.....	710	146	725	130	16
48.....	940	188	975	150	38
49.....	840	163	875	136	27
50.....	1,150	225	1,200	194	31
51.....	960	184	1,012	162	22
52.....	1,180	231	1,250	183	48
53.....	1,260	248	1,300	216	32
54.....	1,000	198	1,040	160	38
55.....	1,225	235	1,350	186	49
56.....	1,100	216	1,210	189	27
57.....	960	198	1,050	166	32
58.....	1,375	267	1,400	230	37
59.....	1,080	216	1,190	197	19
60.....	920	178	1,010	160	18
61.....	1,740	350	1,862	324	34
62.....	1,530	285	1,675	254	31
63.....	990	208	1,050	179	29
64.....	910	182	920	149	33
65.....	980	206	1,100	169	37
66.....	1,000	188	1,075	170	18
67.....	1,080	212	1,212	179	33
68.....	1,130	211	1,225	196	15
69.....	1,100	220	1,162	165	55
70.....	1,680	312	1,725	270	33
71.....	1,285	247	1,350	213	34
72.....	660	148	675	123	25
73.....	1,020	210	1,140	182	28

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Cont.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
613.....	1,180	243	1,210	210	
614.....	1,010	190	1,110	171	
615.....	760	146	825	127	
616.....	830	156	850	131	
618.....	1,145	227	1,150	204	
626.....	1,325	233	1,575	230	
627.....	880	176	925	159	
630.....	1,325	250	1,425	222	
635.....	1,220	224	1,325	225	
636.....	1,385	296	1,436	232	
637.....	870	177	950	152	
638.....	970	196	1,000	180	
640.....	1,450	270	1,550	232	
642.....	830	161	900	146	
643.....	1,385	274	1,460	239	
644.....	930	197	970	171	
645.....	960	198	1,075	176	
646.....	830	161	825	135	
647.....	815	161	875	149	
648.....	1,200	245	1,240	211	
649.....	1,020	194	1,050	158	
650.....	1,840	361	1,900	296	
651.....	1,180	241	1,260	209	
652.....	1,430	290	1,475	257	
656.....	1,130	224	1,200	197	
660.....	950	213	910	160	
662.....	955	189	1,040	158	
668.....	540	106	600	94	
670.....	1,215	214	1,310	199	
671.....	780	143	825	125	
672.....	820	154	885	147	
673.....	1,130	201	1,200	175	
675.....	925	161	975	142	
676.....	970	201	1,025	166	
681.....	1,150	227	1,225	191	
683.....	975	191	1,100	167	
690.....	1,150	230	1,180	191	
692.....	1,400	277	1,500	255	
703.....	1,170	205	1,300	187	
707.....	1,230	246	1,260	237	
709.....	1,005	198	1,125	160	
712.....	1,280	254	1,310	225	
715.....	1,500	294	1,725	265	
716.....	1,070	225	1,130	192	
717.....	1,145	214	1,225	186	
718.....	1,630	294	1,700	268	
719.....	1,100	222	1,225	191	
720.....	1,150	218	1,200	173	
721.....	1,480	278	1,650	258	
722.....	930	179	1,000	148	
723.....	1,270	252	1,450	215	
724.....	1,200	221	1,320	193	
725.....	1,400	258	1,475	195	
726.....	1,170	226	1,225	199	
727.....	1,200	238	1,320	185	
728.....	1,470	250	1,575	220	
730.....	1,340	260	1,590	231	
731.....	1,360	237	1,450	203	

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
2	1,380	237	1,450	197	40
3	1,130	212	1,225	184	28
4	1,280	225	1,325	207	18
5	1,370	228	1,425	211	17
6	1,230	228	1,310	212	16
8	1,300	224	1,560	228	4
9	1,000	301	1,075	248	53
C	2,360	461	2,350	366	95
1	1,110	240	1,240	213	27
2	1,540	316	1,725	279	37
3	1,230	232	1,400	190	42
4	1,040	213	1,150	186	27
6	1,120	224	1,220	190	34
7	1,105	239	1,212	225	14
8	970	207	1,000	172	35
9	1,500	270	1,590	210	60
0	1,060	218	1,125	178	40
1	1,500	276	1,600	230	26
2	1,130	222	1,262	187	35
3	1,230	276	1,290	209	67
4	970	192	950	148	44
5	1,020	203	1,040	173	30
6	1,450	281	1,500	246	35
7	1,380	276	1,390	238	38
8	1,220	233	1,287	188	45
9	1,125	234	1,200	182	52
0	980	184	1,025	160	24
1	960	171	1,040	154	17
2	1,040	204	1,100	172	22
3	713	149	825	134	15
4	1,260	254	1,337	230	24
5	1,040	212	1,075	185	27
6	900	188	962	158	35
7	800	170	825	145	20
8	970	193	1,075	176	23
9	1,025	213	1,090	183	30
0	835	174	880	156	18
1	1,620	318	1,625	266	52
2	960	206	1,100	178	28
3	920	200	1,000	176	24
4	910	180	975	162	18
5	1,355	277	1,435	246	31
6	790	164	875	138	26
7	850	173	887	159	14
8	1,140	228	1,300	205	23
9	730	143	800	125	18
0	960	188	970	171	17
1	940	178	1,060	159	19
2	890	173	937	131	42
3	800	157	840	126	31
4	900	176	1,000	146	30
5	1,060	218	1,200	187	31
6	1,170	207	1,250	177	30
7	1,320	238	1,350	224	14
8	1,185	226	1,275	199	27
9	1,050	223	1,075	185	38
0	1,060	189	1,130	158	31
1	890	162	940	133	29

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
792.....	1,200	202	1,225	149	22
793.....	1,585	292	1,575	252	22
794.....	1,160	225	1,200	199	22
795.....	1,530	272	1,600	233	22
796.....	1,230	231	1,325	222	22
797.....	1,475	265	1,400	224	22
798.....	870	152	910	129	22
799.....	820	167	970	144	22
800.....	970	210	1,037	176	22
801.....	1,020	230	1,050	176	22
802.....	1,205	231	1,275	214	22
803.....	860	160	900	146	22
804.....	910	178	950	141	22
805.....	1,030	202	1,075	183	22
806.....	990	192	1,025	170	22
807.....	1,050	197	1,150	168	22
808.....	1,000	200	1,125	189	22
809.....	1,325	247	1,360	204	22
810.....	1,100	200	1,212	177	22
811.....	1,080	208	1,200	156	22
812.....	1,750	360	1,775	259	22
813.....	1,040	206	1,125	178	22
814.....	1,000	194	1,150	149	22
815.....	750	145	800	121	22
816.....	1,190	207	1,250	192	22
817.....	980	202	1,075	180	22
818.....	920	190	1,062	161	22
819.....	1,420	264	1,550	214	22
820.....	1,130	219	1,275	186	22
821.....	965	197	1,060	165	22
822.....	1,010	198	1,130	163	22
823.....	1,600	317	1,575	270	22
824.....	1,010	206	1,050	183	22
826.....	1,470	309	1,520	267	22
827.....	970	202	1,025	182	22
828.....	1,130	203	1,200	165	22
829.....	1,110	235	1,130	199	22
830.....	1,150	225	1,225	196	22
831.....	1,720	338	1,737	264	22
832.....	1,605	292	1,727	268	22
833.....	1,530	296	1,650	270	22
834.....	1,075	328	1,737	292	22
835.....	1,160	237	1,162	197	22
836.....	1,770	334	1,920	284	22
837.....	1,400	286	1,562	253	22
838.....	1,800	342	1,850	300	22
839.....	1,390	272	1,510	211	22
840.....	1,020	186	1,080	155	22
841.....	1,180	236	1,325	204	22
842.....	1,400	260	1,500	225	22
843.....	1,200	224	1,400	196	22
844.....	1,210	223	1,300	205	22
845.....	1,460	298	1,510	254	22
846.....	1,200	254	1,275	227	22
847.....	1,500	312	1,625	276	22
848.....	1,950	359	1,980	277	22
849.....	1,775	338	1,850	296	22
850.....	1,380	282	1,405	241	22

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
1.	1,170	222	1,250	195	27
2.	935	198	1,000	170	28
3.	1,085	217	1,125	198	19
4.	1,030	210	1,050	189	21
5.	1,070	231	1,150	202	29
6.	1,020	206	1,050	168	38
7.	1,200	242	1,225	215	27
8.	1,230	243	1,370	219	24
9.	1,060	229	1,175	195	34
10.	1,575	263	1,600	275	8
11.	1,230	238	1,350	202	36
12.	1,110	237	1,190	200	31
13.	1,345	266	1,380	242	24
14.	1,310	275	1,420	233	42
15.	1,140	228	1,287	198	30
16.	1,270	212	1,300	185	27
17.	1,030	194	1,050	170	24
18.	1,170	244	1,262	214	30
19.	1,045	226	1,275	199	27
20.	1,040	208	1,137	183	25
21.	1,200	240	1,225	194	46
22.	820	156	825	137	19
23.	1,230	228	1,360	198	30
24.	1,180	234	1,225	193	41
25.	920	180	1,030	144	36
26.	1,150	230	1,225	193	36
27.	1,190	212	1,370	186	26
28.	920	163	950	131	32
29.	760	140	800	115	25
30.	1,100	202	1,200	175	27
31.	1,070	214	1,170	187	27
32.	1,250	282	1,375	220	62
33.	840	159	925	122	57
34.	1,830	306	1,960	305	61
35.	1,090	222	1,160	181	47
36.	1,040	206	1,130	163	43
37.	1,200	242	1,295	210	32
38.	880	186	870	143	23
39.	860	177	925	159	18
40.	1,270	273	1,320	232	41
41.	1,050	214	1,150	177	37
42.	1,180	236	1,300	213	23
43.	1,060	218	1,125	196	22
44.	830	166	850	138	28
45.	830	184	900	158	26
46.	1,130	233	1,262	202	31
47.	830	160	875	149	20
48.	1,150	242	1,270	216	26
49.	930	193	990	174	19
50.	1,110	222	1,100	189	33
51.	950	192	1,030	163	29
52.	880	179	920	145	34
53.	1,090	229	1,112	196	33
54.	1,095	217	1,150	193	24
55.	1,230	246	1,225	200	40
56.	1,210	192	1,275	186	6
57.	1,550	294	1,590	261	33
58.	1,200	226	1,250	208	18



TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Cont.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
910.....	1,000	206	1,020	175	11
911.....	1,240	268	1,240	203	6
912.....	980	196	1,050	176	22
913.....	870	184	950	158	28
914.....	1,070	208	1,150	189	11
915.....	770	160	850	131	21
916.....	950	211	1,025	176	22
917.....	840	166	875	140	26
918.....	1,250	222	1,315	208	11
919.....	1,730	310	1,775	270	11
920.....	1,060	220	1,060	184	22
921.....	1,000	210	1,050	101	11
922.....	1,070	214	1,120	181	22
923.....	1,105	221	1,150	193	26
924.....	1,480	302	1,450	249	11
925.....	1,210	208	1,230	177	11
926.....	850	167	900	144	11
927.....	1,330	245	1,400	216	21
929.....	1,145	213	1,200	187	26
930.....	1,420	242	1,450	203	11
931.....	1,000	160	1,000	152	11
932.....	1,255	238	1,300	208	26
933.....	1,185	199	1,275	173	26
934.....	1,305	237	1,375	206	11
935.....	1,640	299	1,700	252	21
936.....	1,260	242	1,325	202	11
937.....	1,330	255	1,275	194	11
938.....	1,000	184	1,000	158	21
939.....	1,775	351	1,875	304	21
940.....	1,220	261	1,240	216	26
941.....	1,440	282	1,300	208	26
942.....	1,160	225	1,300	208	11
943.....	1,160	234	1,275	204	26
944.....	1,160	242	1,275	217	21
945.....	1,075	226	1,237	201	11
946.....	1,160	239	1,200	197	11
948.....	1,420	258	1,512	230	26
949.....	1,450	273	1,450	226	21
950.....	1,026	191	1,100	156	21
951.....	1,060	196	1,100	168	21
952.....	800	189	990	158	11
953.....	1,140	235	1,220	190	11
954.....	850	170	925	144	11
955.....	910	180	970	151	11
956.....	875	168	950	142	11
957.....	960	196	1,075	161	11
958.....	980	196	1,025	180	11
959.....	1,200	245	1,212	211	11
960.....	1,020	189	1,075	170	11
961.....	1,075	215	1,200	187	11
962.....	810	162	925	146	11
963.....	1,220	239	1,325	202	11
964.....	1,510	302	1,525	259	11
965.....	1,210	242	1,275	216	11
966.....	1,100	229	1,275	199	11
967.....	1,030	206	1,150	177	11
968.....	1,150	214	1,250	182	11
969.....	1,305	240	1,380	226	11

ABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
70	1, 245	232	1, 390	209	23
71	1, 190	234	1, 320	206	28
72	1, 260	267	1, 250	222	45
73	1, 130	210	1, 220	180	30
74	1, 620	330	2, 025	300	30
75	1, 620	301	1, 630	254	47
76	970	199	1, 060	159	40
77	1, 450	270	1, 550	220	50
78	1, 365	238	1, 435	198	40
79	1, 425	308	1, 450	204	44
80	1, 425	274	1, 410	226	48
81	1, 100	205	1, 200	171	34
82	1, 030	202	1, 100	172	30
83	1, 350	265	1, 420	216	40
84	1, 330	264	1, 425	219	45
85	1, 370	225	1, 450	197	28
86	1, 425	268	1, 475	252	16
87	1, 540	256	1, 620	233	23
88	1, 025	205	1, 100	171	34
89	1, 350	259	1, 420	219	40
90	1, 170	197	1, 250	168	29
91	1, 280	248	1, 400	212	36
92	1, 030	208	1, 060	170	38
93	1, 125	225	1, 275	186	39
94	1, 380	262	1, 450	220	42
95	1, 140	234	1, 200	199	35
96	1, 350	270	1, 362	223	47
97	1, 375	261	1, 460	237	24
98	1, 290	280	1, 320	248	41
99	980	198	1, 050	174	24
100	1, 275	265	1, 330	226	39
101	1, 360	265	1, 430	237	28
102	1, 410	276	1, 525	238	38
103	1, 170	243	1, 200	192	51
104	1, 210	237	1, 320	208	29
105	1, 400	280	1, 430	237	43
106	1, 670	331	1, 675	261	70
107	1, 350	270	1, 450	250	20
108	1, 110	242	1, 125	207	35
109	1, 030	208	1, 120	177	31
110	1, 220	234	1, 315	207	27
111	920	189	1, 000	168	21
112	1, 400	269	1, 525	235	34
113	1, 225	250	1, 370	208	42
114	1, 150	212	1, 260	189	23
115	1, 320	246	1, 475	218	28
116	960	192	1, 030	171	21
117	1, 330	248	1, 375	215	33
118	1, 200	226	1, 270	188	38
119	1, 075	208	1, 150	188	20
120	1, 150	230	1, 275	189	41
121	1, 120	210	1, 200	187	23
122	1, 690	338	1, 680	292	46
123	1, 290	258	1, 375	223	35
124	1, 020	194	1, 120	166	28
125	1, 390	234	1, 450	200	34
126	1, 215	248	1, 370	228	20
127	1, 225	238	1, 320	193	45
128	915	174	1, 000	150	24

TABLE IV.—Loss of sugar in grams by individual beets during 98 days' storage—Contd.

Tag No.	Before storage.		After storage.		Loss of sugar.
	Weight.	Sugar content.	Weight.	Sugar content.	
	Gm.	Gm.	Gm.	Gm.	Gm.
1031.....	1,220	227	1,325	207	22
1032.....	880	178	925	153	22
1033.....	1,220	208	1,300	182	22
1034.....	1,090	220	1,190	207	22
1035.....	1,050	220	1,110	184	22
1036.....	1,120	213	1,150	186	22
1037.....	1,655	298	1,680	255	22
1038.....	945	170	975	150	22
1156.....	1,540	262	1,550	236	22
1171.....	1,365	220	1,450	226	22
1184.....	1,275	204	1,275	176	22
1193.....	1,310	231	1,400	210	22
1206.....	1,240	186	1,225	164	22
1207.....	1,130	190	1,175	181	22
1211.....	1,230	256	1,650	224	22
1212.....	2,050	320	2,050	291	22
1215.....	1,010	167	975	140	22
1216.....	1,420	250	1,375	217	22
1224.....	1,365	185	1,350	150	22
1226.....	2,260	344	2,150	318	22
1228.....	1,860	316	1,850	274	22
1231.....	2,250	356	2,075	315	22
1233.....	790	114	800	105	22
1245.....	1,325	244	1,330	210	22
1254.....	2,340	356	2,350	348	22
1255.....	1,570	273	1,550	254	22
1256.....	1,400	218	1,425	202	22
1257.....	1,305	210	1,325	204	22
1258.....	1,480	252	1,480	210	22
1259.....	1,155	201	1,170	185	22
1266.....	1,490	241	1,475	206	22
1272.....	1,210	201	1,200	173	22
1273.....	1,530	257	1,500	219	22
1282.....	1,600	260	1,600	246	22
1289.....	1,180	203	1,160	165	22
1302.....	1,450	255	1,435	224	22
1315.....	1,315	213	1,325	193	22
1318.....	1,390	250	1,400	216	22
1323.....	1,160	160	1,175	148	22
1328.....	1,575	265	1,625	247	22

The results here given indicate that beets are irregular in gain or loss of weight during storage. Most of the beets gained slightly in weight. Some few remained constant as to weight, while others lost in weight. While the mere loss or gain in weight, due to water outgo or water intake has its effect upon the percentage of sugar, it does not influence the sugar content of the beet.

Of most consequence is the marked irregularity in the amount of sugar lost by individual beets during storage. This loss of sugar ranges from 0 to 154 gm.; that is, from 0 to 50 per cent of the total sugar content of the beet at harvest. Column 6 of Table IV gives the extent of this loss of sugar for each individual beet. Some of the reasons and conditions

leading to this loss of sugar will be given in a later paper on the storage of sugar beets.<sup>4</sup>

Table V gives the correlation between sugar content of beets and loss of sugar in grams during storage.

TABLE V.—Correlation between sugar content of beet in grams and the loss of sugar during storage

Sugar content in grams.	Loss of sugar in grams.							
	1 to 20	21 to 40	41 to 60	61 to 80	81 to 100	101 to 120	121 to 140	141 to 160
100 to 150.....	27	15						
151 to 200.....	82	157	6	1				
201 to 250.....	56	213	43	2	2			
251 to 300.....	12	86	32	10				
301 to 350.....	2	13	19	3				1
351 to 400.....	1	2	3	3	2	1		
401 to 450.....								
451 to 500.....					1			

The value of the coefficient is  $0.476 \pm 0.018$ , which indicates a practical certainty of correlation. The table shows in a general way the fallacy of testing sugar beets after storage and explains how a breeder's lines selected from such tests may continue to fall in sugar content with succeeding generations.

Table VI gives the correlation between the percentage of sugar in the beet at harvest and the loss of sugar in grams during storage. The value for  $r = 0.366 \pm 0.020$ .

TABLE VI.—Correlation between percentage of sugar in beet and grams of sugar lost during storage

Percentage of sugar in beet.	Loss of sugar in grams.															
	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90	90 to 100	100 to 110	110 to 120	120 to 130	130 to 140	140 to 150	150 to 160
13 to 14.....			1													
14 to 15.....	1	1	2	1	1											
15 to 16.....	4	6	5	1	2											
16 to 17.....	6	10	12	7	2	2										
17 to 18.....	9	25	26	27	10											
18 to 19.....	0	31	58	45	15	8	3		2							1
19 to 20.....	3	26	65	51	27	6	5	3	1	1						
20 to 21.....	2	16	71	75	24	5	3	2	1		1					
21 to 22.....		7	27	18	9	1	2									
22 to 23.....			2	3	2	2	2									

<sup>4</sup> PACK, D. A. STORAGE OF SUGAR BEETS. (Unpublished.) 1923.

## DISCUSSION

Since sugar-beet factories cut their beets at harvest or after a short period of storage, the sugar-beet industry requires beets of high sugar content at harvest. This fact and the results of these investigations demand that our mother beets be tested in the fall after harvest. Since the average commercial sugar beet of the factories is stored 40 days on an average before cutting to make sugar, it might be advisable to test our breeding beets 40 days after harvest. In this event we should be selecting breeding beets which would be of high sugar content at harvest and have some storage qualities as well. Thus we would select with the expense of one testing those beets which would be most desired by the sugar companies. Under no circumstances would it appear advisable to make only one test on mother beets, and this test in the spring after the beets have been stored.

If there comes a time when sugar companies are forced to store their beets over extended periods, those having good storage qualities will be desired, in which event beets containing such qualities can be selected and bred up from consistent tests made before and after storage.

## SUMMARY

1. Failure to recognize the erratic variations between tests of sugar beets at harvest time and after storage until the following spring has probably led to confusion in the selection of desirable strains of beets in sugar-beet breeding work.
2. Spring tests of sugar beets (made after the beets have been stored) are incomparable with the tests made at harvest. Spring tests are untrustworthy and give erroneous values for the quality of the beets at harvest.
3. Individual beets show great irregularity in the percentage and quality of sugar lost during storage.
4. Beets high in sugar and sugar content tend to lose more sugar during storage than do beets which are low in sugar and sugar content.
5. Since sugar-beet factories cut their beets at harvest or within an average period of storage of approximately 40 days, it appears that strains selected as desirable for breeding purposes should be considered on the basis of fall rather than of spring tests.
6. In order to understand clearly the comparative value of different strains of beets, the plant breeder should record both fall and spring tests and the conditions under which the beets were stored.

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